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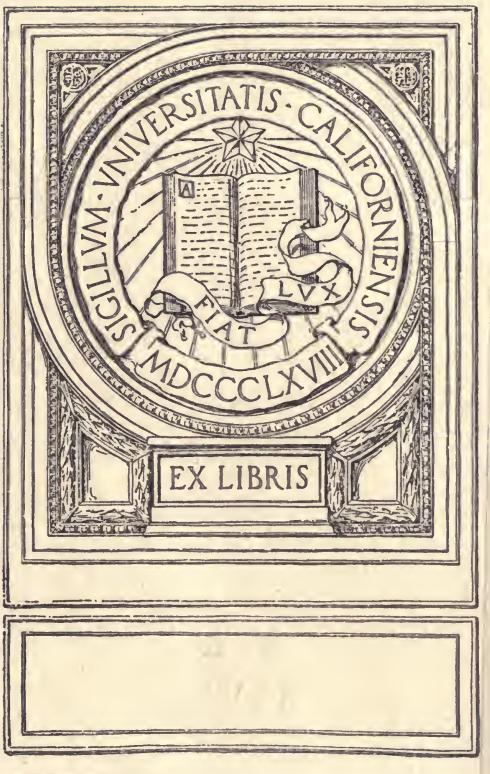
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SURGERY

AT A

CASUALTY CLEARING STATION

BY

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PREFACE

SOME months ago it was suggested that the type of surgical work which is associated with the Casualty Clearing Station might with advantage be summarised in book form. The present volume is the outcome of that suggestion. It embodies the results of several years' experience of this type of work on the Western Front, and as far as possible care has been taken to include in the text only methods of proved value.

In a book of this description it is impossible to fully acknowledge the assistance and many courtesies which we have received. We are indebted to many administrative officers of the R.A.M.C. for the facilities which they have granted in clinical and pathological work. Colonel Lister, C.M.G., A.M.S., has been good enough to revise the chapter dealing with injuries to the eye. To Captain Oswald Robertson, M.O.R.C., U.S.A., we are indebted for permission to quote from his work on blood transfusion; and to the Medical Research Committee, the proprietors of the *British Medical Journal* and the *Lancet* we owe thanks for permission to reproduce certain illustrations. Many of the drawings

with which the book is illustrated have been executed by Mrs. Fraser; the Index has been compiled by Surgeon M'Bain Ross, M.C., R.N.

We desire to thank the Publishers for their courtesy and attention.

CONTENTS

CHAPTER I

PAGE

The Organisation and Arrangement of the Casualty Clearing Station 1

CHAPTER II

Surgical Shock 7

CHAPTER III

General Wounds and their Treatment . . . 23

CHAPTER IV

Antiseptics 62

CHAPTER V

Gunshot Injuries of Bones 74

CHAPTER VI

Wounds of Joints 131

CHAPTER VII

Abdominal Wounds 144

CHAPTER VIII

Chest Wounds 190

CHAPTER IX

PAGE

Abdomino-Thoracic Wounds 207

CHAPTER X

Injuries to the Head 211

CHAPTER XI

Injuries to the Spine 229

CHAPTER XII

Lesions of the Peripheral Nerves 238

CHAPTER XIII

Haemorrhage and Wounds of the Blood-vessels . . 241

CHAPTER XIV

Gas Gangrene 252

CHAPTER XV

Amputations 262

CHAPTER XVI

Transfusions and Infusions 269

CHAPTER XVII

Injuries to the Eyes 300

CHAPTER XVIII

Tetanus 304

INDEX 313

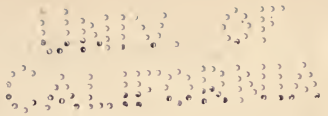
LIST OF ILLUSTRATIONS

FIG.		PAGE
1.	Various types of rifle bullets	24
2.	Various types of fragments of high explosive shell	25
3.	Wound of ankle caused by the lateral impact of a bullet	30
4.	Gutter wound of upper arm	32
5.	The various instillation tubes used in the Carrel technique	51
6.	Glass ampoule used in the Carrel technique	52
7.	Various types of distributing tubes for use in the Carrel technique	53
8.	Bed-foot provided with upright for attachment of ampoule	55
9.	Scheme of distribution of fluid to an extensive wound of the calf	56
10.	Glass ampoules provided with connecting and distributing tubes	57
11.	Secondary closure of wound edges by coaptation with strips of sticking plaster	58
12.	Secondary closure of wound edges by laced flannel strips	58
13.	Method of applying glued gauze extension to the limb	90
14.	Hey Groves' horse-shoe screw clamps	92
15.	Finochietto's stirrup extension apparatus	94
16.	Thomas knee splint—bed pattern	100
17.	Thomas knee splint as applied on the field for compound fracture of the femur	105
18.	The Wallace-Maybury splint	110
19.	The Balkan frame	111
20.	Hodgen's wire cradle splint	113
21.	The fixed wire cradle splint	114
22.	The abduction frame splint (Jones)	115
23.	The abduction frame splint interrupted opposite the left hip on account of a wound in this position	116

FIG. PAGE

24. Frame for transport of cases of double fracture of the femur (Hey Groves) 117
25. Sinclair's splint for compound fracture of the ankle-joint . 119
26. Sinclair's ankle splint applied 120
27. Crab splints for use in compound fractures of the foot and leg 123
28. Jones angular splint for compound fracture of the humerus . 126
29. Straight arm splint of the Thomas pattern . . . 127
30. The modified Borchgrevink splint (Hey Groves) . . 127
31. A variety of crab splint for use in compound fracture of the elbow-joint 128
32. Hepburn's splint 140
33. A variety of crab splint for use in cases of compound fracture in the region of the ankle-joint 143
34. Bullet wound of the greater curvature of the stomach . 165
35. Bullet wound of small intestine, showing the rosette appearance of the exit wound 167
36. Multiple bullet wounds of the small intestine . . 168
37. Bullet wound in long axis of the small intestine . . 169
38. Multiple wounds of the small intestine caused by small bomb fragments 169
39. Shell wound of small intestine with shell fragment embedded in the wall of the gut 170
40. Shell wounds of small intestine showing extensive destruction of the gut 171
41. Shell wound of liver, showing the fissuring character of the lesion 181
42. Bullet wound of spleen 184
43. Tangential bullet wound of spleen 185
44. Gutter wound of scalp, with gutter fracture of vault . . 212
45. Diagrammatic representation of a gutter fracture of the cranium 213
46. Diagrammatic view of penetrating wound of skull . . 214
47. Penetrating wound of skull with retained foreign body . 216
48. Diagrammatic view of perforating wound of skull . . 216
49. Impact fracture of skull with uninjured dura . . . 217
50. "Isle of Man" skin incision 221
51. Carrel-Gentile syringe 223

FIG. PAGE
52. Diagrammatic view of the method of closure of the deep surface of the excised scalp wound 225
53. The bevelled flap method of closing defect in the scalp (Cuthbert Wallace) 226
54. Pezzer's self-retaining supra-pubic tube . . . 236
55. Dorrance's arteriorrhaphy suture 249
56. Dorrance's suture in end-to-end anastomosis . . . 249
57. Diagrammatic view of a recommended method of amputation 264
58. Different views of containers for use in blood transfusion . 286
59. Diagrammatic view of the method of blood transfusion by means of the paraffined receiver 288
60. Citrate transfusion apparatus 290
61. Bleeding bottle for preserved blood 296
62. Apparatus for syphoning off supernatant fluid . . 297
63. Apparatus for transfusion of preserved blood . . . 298



CHAPTER I

THE ORGANISATION AND ARRANGEMENT OF THE CASUALTY CLEARING STATION

THE Casualty Clearing Station is somewhat of an innovation in the organisation of the British Army Medical Service; it was first employed in active warfare in the early days of the present war. During the South African Campaign of 1899–1901 a somewhat corresponding unit existed in the shape of the Field Hospital, and when, after the campaign, the Army Medical Service underwent some degree of re-organisation, the Field Hospital was replaced by a unit which was termed a Clearing Hospital, and at an early stage in the present war the designation of Casualty Clearing Station was substituted for that of Clearing Hospital.

The Casualty Clearing Station is a unit which is specially set apart for the evacuation of the sick and wounded collected by the ambulances, and to look after wounded or sick men until they can be sent to the Base or returned to duty. "It is a pivot upon which the removal of sick and wounded turns, and is the central point to which the collecting zone converges and from which the evacuating zone and distributing zone diverge."[1]

In accommodating Clearing Stations to the new and unexpected conditions of modern warfare, these units have undergone

[1] R.A.M.C. Training, 1911, p. 125.

considerable alteration during the course of the present war. Originally they were prepared for the accommodation of 200 sick or wounded. As the name implies, they were essentially intended as Clearing Stations; patients admitted were rested, fed, and suitably clothed for their further journey; their wounds were examined and re-dressed, while a certain proportion of the very slight cases were possibly retained for return to duty; the most serious cases, who could not stand the further immediate journey, were retained at the Station. It was intended that only the most urgent operative procedures should be carried out, and the personnel, equipment, and accommodation were arranged accordingly.

The Clearing Hospital of to-day is very different from its original model. The accommodation has been increased so that there are many Stations which can accommodate 1000 sick and wounded, and nursing sisters are now almost invariably included on the Staff.[1] The equipment provided is such that any reasonable operative procedure can be carried out, and when it is desirable, cases may be retained under treatment for a period up to three weeks. In fact, a Casualty Clearing Station is now upon very much the same basis as a Stationary Hospital, with certain distinctions. The Clearing Station is included as one of the front units as distinguished from units on the Lines of Communication or at the Base. Its accommodation and equipment are such as to permit of great elasticity; it should be capable of mobility at short notice. For slight cases it retains its function as a collecting and distributing centre, for more serious cases it forms the site at which they receive their first serious surgical and operative attention, and in which they are detained until they are on a fair way to recovery.

[1] The latest arrangement is that a C.C.S. provides officially for 200 beds on the Stationary Hospital basis, and 800 on C.C.S. basis, or with stretchers (Official Circular).

It is difficult to lay down any scheme regarding the arrangement of a Casualty Clearing Station. The plan will vary according to whether the unit has found its accommodation in permanent buildings, in hutments, or in tents; but it is advisable to give an outline of the essential arrangement which is necessary for rapid and satisfactory working.

A Casualty Clearing Station is divided into Reception, Operation, Retention, and Evacuation Areas.

Reception Area. — When cases are admitted they are collected in what may be termed "Reception Rooms," and it is advisable to have these subdivided into accommodation for lying cases and accommodation for sitting cases. As each case enters, a note is made of the name, number, and unit of each, of the type of wound, and of the date of entry. For facility of registration and subsequent evacuation a counterfoiled serial number is attached to each patient, and when the patient is evacuated the serial number is removed, and so a check entry is kept of each individual case.

Sitting Cases.—The sitting cases are collected for examination and observation by a Medical Officer, and while this is being arranged each sitting case is provided with food and a hot drink. After examination by the Medical Officer, and after the wound has been examined and treated, the cases are distributed to the various wards which have been provided for their accommodation; in addition, every case which has not hitherto received an injection of anti-tetanic serum now receives an injection. It is possible that this examination reveals the fact that a certain number of these cases ought to be classified as "lying" cases, and they are now transferred. A "sitter," if thought fit, is passed to the "evacuation area," if not fit, to the "retention" or "operation" area.

Lying Cases.—These are generally collected by themselves in a special part of the reception area—when they are carefully examined and if necessary dressed. It is possible that some

which were considered to be lying cases can now be classified as "sitters." The great majority of lying cases, however, will be distributed to the retention and operation areas.

Distribution of Cases.—As the cases are distributed, it is well to pin upon each stretcher a slip of paper stating the nature of the wound, whether operation is necessary, and whether any special treatment has been already carried out. Attention to this detail will frequently prevent delay or confusion in the after treatment.

It may be said that the cases for distribution pass into one of three separate channels: (1) Cases which require operation either immediately or at the earliest possible opportunity. The majority of cases pass into this group, and they are collected in a pre-operation ward (operation area). (2) Cases which require early operation, but the condition of which is too serious to permit of disturbance until some degree of recovery has taken place. These are best distributed in what may be termed the "Resuscitation Ward" (operation area); a ward in which every possible means is taken to restore the patient and render him fit for operation — warmth, gum infusion, blood transfusion, etc. (3) Cases which do not require any immediate operative attention, and which are distributed to either the retention or the evacuation area.

Examination of Cases.—In carrying out the examination of these cases it is a good rule to effect as little disturbance as possible, avoiding especially such a manipulation as turning the patient repeatedly on his side; the blood pressure of a seriously wounded man is often extremely low, and even the disturbance of turning him may induce a fatal collapse.

Special attention should be paid to the examination of buttock and high thigh wounds; these are frequently complicated by injury to the abdominal or pelvic viscera, and a superficial examination may easily overlook such a complication.

If a tourniquet is in position, it should be loosened gradually

and with care; in the great majority of cases it will be found that the bleeding has ceased, and if a tourniquet can be dispensed with, the chances of saving a limb may be greatly improved. An imperfectly applied tourniquet may, by producing venous congestion, increase rather than diminish the bleeding. If a main vessel has been damaged, the result will probably be apparent on the gradual slackening of the tourniquet, in which case it can be immediately re-applied. If there has been any possibility of the original bleeding having been serious, it is wise to have the loosened tourniquet in such a position that it can be immediately re-applied. While the patient is awaiting operation the dressing should be examined from time to time; there is a danger of the bleeding being re-established during the period of reaction and while the blood pressure is being re-established.

Special care should be exercised in the examination of scalp and skull wounds, and of wounds in the neighbourhood of the abdomen or perineum. The presence of too tight splints or bandages should be looked for and corrected.

Operation Area.—The operation area consists of a pre-operation ward, a resuscitation ward, and operating theatres.

Pre-operation Ward.—The greatest care should be given to the arrangements of the pre-operation ward. There, each case should have his clothes, if possible, entirely removed; his skin, if wet, rubbed dry; and the wound examined and re-dressed. Clean stretchers, well supplied with blankets, have been already prepared, and to these the cases are now transferred.

Great comfort and warmth can be obtained by employing three blankets on the stretcher, arranged in such a way that there are four folds beneath the patient and four folds above. Such an arrangement permits of the blankets being tucked thoroughly around the patient. Every effort should be made to have the prepared stretcher already warmed, either by an electric cradle, by hot bottles, or by placing a small oil stove

beneath the stretcher. If the condition of the patient permits, warm nourishment of some description may be given.

Resuscitation Ward.—This is arranged on the principle of an ordinary ward. Special attention is paid to the lighting. This should be as good as possible, as intravenous infusions are continually being given, and imperfect lighting may render the operation very difficult.

Operating theatres, retention, and evacuation areas require no special comment.

CHAPTER II

SURGICAL SHOCK

Shock is one of the most frequent and one of the most distressing complications of war wounds. It is responsible for a large mortality, and it prejudices and sometimes obviates operative interference. Probably under war conditions it is seen in a more intense form than is ever witnessed in civil practice.

Theories of Origin.—There has been great difficulty in explaining the origin and development of shock; and, as is always the case in these obscure conditions, attempts to elucidate the mystery have resulted in the formation of a number of theories. It may be of interest to mention some of the views which for a time found acceptance. Crile and Mummery believed that the essential fault lay in an exhaustion of the vasomotor centre of the central nervous system, with a resulting accumulation of blood in the large venous sinuses of the abdominal cavity, and a secondary weakening of the heart's action. Crile advanced the view that as a result of progressive sensory stimuli a degree of degeneration or chromatolysis occurred in certain nerve cells of the central nervous system — more especially in Purkinje's cells of the cerebellum—with resulting general bodily exhaustion and changes in the liver and adrenals.

Yandell Henderson brought forward his theory of Acapnia. He believed that painful stimuli induced deep respiration, so

deep as to give rise to an excessive loss of CO_2. The resulting diminished amount of CO_2 in the blood led to a want of stimulation of the respiratory centre, a fall of venous blood pressure, and an accumulation of blood in the larger venous trunks.

Cobbett and Vale stated that they found a distinct concentration of the blood in shock—a condition to which they applied the term Oligaemia, and which they believed depended upon a loss of fluid from the blood into the body tissues. The resulting increased concentration and diminished volume of the blood led, they believed, to weakening of the heart's action.

Boise's theory held that shock was essentially a cardiac affair, and depended upon an arrest of the heart's action in systole, and a resulting fall in blood pressure. He appears to have based his theory mainly on the fact that animals dying in shock showed contraction of the ventricles, and his treatment consisted in the administration of veratrum veride, which lessens systole.

Meltzer believed that a loss of intestinal peristalsis led to an accumulation of blood in the veins of the abdominal cavity, and for a time it was believed that exhaustion of the adrenal bodies played an important part in the initiation of shock.

The multiplicity of the theories is sufficient evidence of the obscurity of the condition. It is possible that a considerable source of error has arisen from the persistent statement that in shock the outstanding feature is the accumulation of blood in the larger venous channels of the abdomen. Such a statement may be true where shock is experimentally produced by exposure and handling of the abdominal viscera, but then it is an artefact produced by direct irritation. Accumulation of blood in the abdominal veins is certainly not a feature of clinical shock, as we have shown repeatedly when performing laparotomies upon men wounded in the abdomen and suffering from shock.

Origin of Shock.—*Predisposing Factors.*—In discussing the

origin of shock there are predisposing factors which must be mentioned. There can be no doubt that there are certain conditions which, if fulfilled, render one man more liable to shock than another.

The first of these is the possession of a highly strung or so-called "nervous" temperament. It is difficult to appreciate the degree to which this is potent, but it certainly plays a part in the severity of what we shall afterwards call "primary shock."

The second, and probably the most powerful, predisposing factor is cold; and this has been proved beyond any question of doubt. A "cold" man—with his body temperature lowered from wet or from exposure—is in a peculiarly susceptible condition to the development of shock. The explanation of this will be dealt with later when we discuss the clinical features of the change.

Other predisposing factors are—fatigue, shortage of food or of water, and perhaps to some extent, immediate mental anxiety.

Direct Etiological Factors.—As regards the exact etiology—and here at once one comes against a difficulty—one cannot put one's finger upon any single factor and say that there is the essential etiological basis. If one is dealing with phthisis for example, one can say that the essential etiology is an infection of the lung with the tubercle bacillus; but in shock, with our present knowledge, any correspondingly definite statement is impossible. We shall therefore describe the clinical features of a typical case of wound or traumatic shock, linking up the clinical features with what we know of the pathological findings.

Clinical History.—Let us follow the case of a hypothetical soldier. This man is one of the garrison of a portion of front line trench. Let us assume that the predisposing conditions are such as we believe to be favourable to the development of

shock, that is to say, the man is chilled, fatigued, and with less in the way of food and drink than the average man receives.

Now, let us suppose that this man receives a wound of moderate severity, and to pursue the hypothesis, let us assume that he has sustained a shell wound of the thigh with considerable damage to the soft parts, but without injury to bone. As soon as the wound is sustained, the man may demonstrate the features of what we term *Primary Wound Shock.* He becomes pale, a profuse general perspiration breaks out, and in some instances he may actually lose consciousness. If his pulse rate is taken it will be found to be slightly increased. Respiration rate shows no alteration. Blood-pressure readings show a somewhat increased or a normal level. The man generally complains of feeling chilled and may shiver. The features grouped together constitute the condition which may be termed *primary shock*, and they are almost certainly the result of a powerful nerve stimulus. The pallor may be the result of a general vaso-constriction, and the rise in blood pressure may have the same origin. It is possible that the sweating is the result of a sympathetic stimulation.

The wounded man now passes into the hands of the regimental stretcher-bearers. His wounds are dressed by the regimental medical officer if he is at hand, or by the stretcher-bearers, and he is placed upon a stretcher. If a blanket is available he is covered with it, but frequently he has no covering beyond the clothes which he is wearing.

Now there probably begins what may be a long and difficult carry to the Regimental Aid Post, and during this journey he becomes more and more chilled. He may be experiencing the cold of a winter night; and the evaporation of sweat and moisture from his wet clothing still further reduces his body temperature. By the time he reaches the Regimental Aid Post his condition has altered, he is thoroughly chilled, his blood pressure is lowered and it is continuing to fall. His pulse rate is rising.

In appearance he is pallid and rather haggard-looking. At the Aid Post restorative measures in the shape of warmth and stimulant are probably applied, but, for the sake of our description, let us assume that these are neglected. Another stage of his journey now begins, the stage to the Advanced Dressing Station of the Field Ambulance. Under certain conditions this portion of the journey may be completed in an ambulance car; most frequently it has to be done by wheeled stretcher over the open. It must be remembered that all this time the patient is exposed to danger in the shape of shell-fire and machine-gun fire. His condition at the Advanced Dressing Station will be found to be worse than it was at the Aid Post. The chill has deepened; the body temperature is lower; the pulse has quickened and become feebler; his blood pressure continues to fall, and there is general pallor; his extremities may be bluish, and this is particularly noticeable in the finger-nails. The further stages of his journey are always completed in ambulance cars, either direct to the Casualty Clearing Station or to the Casualty Clearing Station *via* the headquarters of the Field Ambulance. He arrives at his destination in a condition of definite established shock. To this gradually developing group of symptoms we have applied the term *Secondary Wound Shock.*

At the Casualty Clearing Station such a case presents definite features. He is pale, collapsed, and generally apathetic; the body may be bathed in perspiration. By one's hand one appreciates the "dead" coldness of the body surface. The breath is cold, showing that internal respiration is reduced to a minimum. In many cases the extremities are bluish; the body musculature is relaxed; the respiration rate is increased; the pulse rate has markedly increased; and the pulse at the wrist may be imperceptible. When the blood pressure is read, both the systolic and diastolic readings are found to be low. He often complains of thirst. If the con-

dition is very serious, or if it is neglected, death rapidly supervenes. There may be restlessness with rapid urgent breathing and eventual cardiac failure. Sometimes the respiratory distress and restlessness are absent, and death comes very gently. As a rule there is complete consciousness almost to the end. Such is the clinical history of a typical case of shock as traced from its commencement. It is important to remember that while the features we have described are developing, two other processes are almost certainly going on: these are (1) slight but progressive haemorrhage, and (2) some degree of sepsis. This fact must be kept sight of, as these complications have an aggravating influence upon the developing shock. It is an amazing complexity of features, but investigation of cases of established shock provides certain findings, and it is possible from these to build up an idea of what the sequence of events has been.

Certain Pathological Findings.—In dealing with the clinical features we have mentioned the rapid and feeble pulse, the quickened respiration, and the low blood pressure. Examination shows other features. The first of these is a disparity between the red blood cell counts taken from the skin and mucous membrane capillaries, and between the counts of the capillary cutaneous vessels and the veins of the skin.

Capillary blood drawn from an exposed portion of the body may show a count two millions in excess of blood drawn directly from a cutaneous vein. The capillary count appears to be higher in the more distal portions of the extremities, and it would appear to be augmented by cold. It is certain that a capillary count from the warm mucous membrane of the mouth is much more closely approximated to normal than a capillary count from the ear or finger. In other words, there is a concentration of blood in the capillary area of the exposed portions of the body, and with the concentration there is a stasis. The other factor which examination shows is a decrease

in the alkali of the blood, or, put in another way, an increase of the H. Ion concentration. In other words, an acidosis develops, and it may be accepted as a safe rule that the lower the blood-pressure readings the more marked is the acidosis likely to be.[1]

Possible Sequence of Events.—It may be said that a shocked man is characterised by the following features: A rapid imperceptible pulse, a low blood pressure, a depressed body temperature, and sometimes by a decreased alkalinity of the blood and body tissues. Remembering and recognising these facts, let us attempt to build the whole sequence together, as it is demonstrated in a condition of wound shock.

Immediately following the infliction of the wound, a powerful stimulus occurs, and is evidenced by certain distinct features in many respects similar to an exaggerated fainting. In all probability the stimulus is followed by a period of reaction, during which the resistance and vitality of the man are lowered. This is primary wound shock, and its degree may be slight or severe. Often there is complete recovery from it, sometimes it may pass imperceptibly into the condition of secondary wound shock.

It is probable that there are two processes which introduce the condition of secondary wound shock. The first of these is a loss of fluid from the blood by sweating, with a resulting increased concentration of the blood; the second is the effect of cold in producing a concentration and a stasis of blood in the peripheral capillary circulation: the former may not be of great importance, the latter factor is certainly important.

The concentration and stasis of blood in the peripheral capillary circulation would appear to be the first stage in the

[1] Recent investigations have shown that the importance of acidosis in shock may have been over-estimated. Bayliss in the Oliver Sharpey Lectures, April 30 and May 2, states: "On the whole I am compelled to conclude that acidosis is not in itself a serious factor in shock."

process of secondary wound shock, and we believe that the phenomenon is largely the effect of chilling of the body surface and perhaps to an inferior extent the result of profuse sweating. The concentration as shown by the red blood cell count is borne out by haemoglobin and haematocrit readings.

The effect of the concentration of blood in the capillary area may be that a considerable amount of the fluid blood is thrown out of active circulation; there is a diminution in the return of blood to and in the output of blood from the heart, and a weakening of the heart's action with a resulting fall in blood pressure.

An increase of the H. Ion concentration of the blood may now begin to appear. It is difficult to say why it should occur. Probably it is dependent upon a number of factors—the previous fatigue, perhaps long periods without food, cold, haemorrhage, and the diminished body blood supply resulting from the loss to the general circulation of the blood which has become stagnant in the capillary areas. This last factor will lead to an imperfect oxidation of the products of tissue metabolism and will give rise to an increase of the H. Ion elements of the blood.

As the acidosis develops it tends progressively to lower the blood pressure, while the low blood pressure in itself aids the progressing acidosis. In fact a vicious circle or a series of vicious circles are now in process of being established: the acidosis leads to a further fall in blood pressure, and the lowering of the blood pressure tends to increase the acidosis. The lowered blood pressure and the acidosis aggravate the peripheral stasis of blood, and more and more blood will pass out of active circulation. This will result in a still further fall in blood pressure, and so the whole process is maintained and augmented.

To sum up the position, a man in a condition of established shock is in such a state because a considerable portion of his

blood is out of general circulation by having become stagnant and concentrated in the peripheral capillary circulation; because there is a diminution in the alkali of his blood—a developing acidosis;[1] because his heart's action is impaired and his blood pressure lowered; and because as a result of these several conditions his whole metabolism is altered, his vitality depressed, and his tissue oxidation deficient.

As we have already said, during the development of shock two other features may be in evidence — a progressive haemorrhage and a gradually increasing local sepsis. Both of these will act by lowering the blood pressure and by directly increasing the acidosis which is present.

Diagnosis of Shock.—There are certain conditions which are allied to shock and so far resemble it as to cause possible confusion, but it is important to make a differentiation.

Haemorrhage is apt to be confused with shock, and of course the two conditions are interdependent: one may put it that haemorrhage cannot exist without some degree of shock, but shock may exist without haemorrhage. The history is generally sufficient to exclude or suggest the possibility of hæmorrhage.

Acute Anaphylaxis has been confused with shock. It follows an injection of anti-tetanic serum, and it is generally recognisable by its intimate relationship to the injection.

Gas Gangrene. — The toxaemia which results from the infection of a wound with the organisms of gas gangrene may be mistaken for the development of shock. It is recognised by the local condition of the wound and by the period at which the symptoms appear.

[1] Since the above was written it has become apparent that the relation of acidosis to shock must be reconsidered.

Several observers have shown that shock may be present without acidosis (Keith), and conversely that considerable acidosis may exist without shock (Bayliss, Dale, Richardson).

Prognosis of Shock.—It is advantageous to have certain guides in estimating the chances of recovery of patients suffering from shock. The prognosis is grave when secondary shock appears early, when it rapidly deepens, when it is associated with the complications of haemorrhage and sepsis, and when it is of the type distinguished by restlessness and severe respiratory disturbances.

Failure of reaction to warmth and stimulation almost invariably means a fatal termination.

Treatment of Shock.—To secure the best results, treatment must begin at the earliest possible moment, and at its commencement it ought to be preventive rather than therapeutic.

Preventive Treatment.—Undoubtedly the greatest preventive of shock is warmth, and if the body temperature is maintained throughout, it is unlikely that shock of any severity will develop.

Some one has said that a shocked man becomes for the time something like a cold-blooded animal. He takes the surrounding temperature, and he requires artificial warmth to set his "chemistry" going again.

Every precaution should be taken to prevent the patient being chilled—warm blankets, hot bottles, and warm drinks are all made use of. Lieut.-Colonel E. M. Cowell has suggested that each stretcher in use in the front line should be provided with a blanket wrapped in a waterproof sheet. At the Regimental Aid Post more blankets and hot bottles are added, and the stretcher may be warmed by putting a small oil or Primus stove beneath it; the stretcher resting on trestles. Keeping in view what we have said in regard to the reduction of the blood alkali, warm drinks should contain an alkali. It is found that 8 drachms of sodium bicarbonate to the pint of sweetened tea or coffee makes quite a palatable mixture.

Judgment is required in deciding whether to remove wet clothing. The need is not great so long as the patient can be

got warm. It may indeed be harmful if conducted in a cold atmosphere, both on account of the exposure and disturbance of the patient. If a long wait is anticipated it should be done. Before sending the patient away a hot bottle should be placed on each side of the chest so that the bottom of the bottle rests on the stretcher between the body and the arms. Another should be placed across the groins.

Morphia is best given beneath the skin. It is beneficial only in the relief it affords from pain and anxiety. The amount given should be strictly limited—a $\frac{1}{4}$ grain under the skin is usually sufficient. Time should be given it to act. Morphia given by the mouth is apt to act slowly.

The same attention to warmth is paid throughout every stage of the journey to the Casualty Clearing Station.

Great care is taken that bleeding is not occurring from the wound. What may appear to be only slight oozing eventually has a very considerable cumulative effect. Fractures are carefully splinted, and all unnecessary sensory disturbance is avoided. If attention is paid to these details the chances are that the wounded man arrives at the Casualty Clearing Station in a good condition. Occasionally, however, it is impossible to carry out these instructions, as during the progress of a big battle.

Treatment of existing Shock.—Warmth is again one's main stand-by. The patient's wet clothing is removed, the body surface is dried with warm towels, warm clean pyjamas are put on, and the man is placed in a bed which has been thoroughly warmed by an electric heater, by hot bottles, or hot air. To begin with, at any rate, warmth should be given a clear field of opportunity, and the patient should not be disturbed by any other form of treatment. If there is to be an improvement it will be apparent at the end of the first hour. It has been suggested that there may be a mechanical advantage from raising the foot of the bed. We have not seen any benefit result from it;

on the other hand, it is rather disturbing to the patient. If at the end of an hour the blood pressure still remains low and no improvement is apparent, further measures must be taken, and one's efforts are directed towards raising the blood pressure.

A high blood pressure is not our object for its own sake. We wish to increase the blood supply and oxygen supply to the tissues, especially to vital organs such as the nerve centres and the heart. The correct way is to increase the volume of blood in circulation. This involves a raised arterial pressure without decreasing the peripheral blood-flow, and therefore the use of vaso-constrictor drugs is to be deprecated, as they raise the blood pressure by narrowing the arterioles which convey the blood.

It is but natural that transfusion of compatible human blood is the most desirable means of securing our objective, and this method is being adopted more widely than ever before. Full details of the method are discussed in the chapter on Infusion and Transfusion, page 269.

There are, however, circumstances in which blood transfusion may be impossible, and under such conditions there are certain substitutes which may be employed. The various details regarding these are discussed later (page 275), and at this stage it is sufficient to state that by far the most reliable substitute has been found to be a solution of 6 per cent gum acacia in water or normal saline. The suggestion that this substance should be employed was originated by Professor Bayliss of University College, and in actual practice its employment has yielded excellent results.

The method of preparation of the solution is dealt with later. The intravenous infusion is given slowly at body temperature, fifteen to twenty ounces at a time, and infused slowly. The injection yields its best results when the blood volume is reduced by haemorrhage, but it is of great value in cases of pure shock.

Ringer's solution has been found to be useless as a means of raising and maintaining the blood pressure. It leaves the vessels in the course of an hour or so, when the blood pressure returns to its former level or even lower.

Hypertonic saline was used with the object of preventing the rapid escape of fluid from the vessels by means of its osmotic pressure. But it will do this only so long as the salt content in the blood remains higher than that of the tissue fluid. Since salts diffuse through the walls of the blood-vessels at a great rate, this concentration rapidly becomes equal on both sides, and then the conditions are the same as with Ringer's solution.

Alkaline solutions—4 per cent sodium bicarbonate—are advocated in view of the "acidosis" which is present in wound shock. In practice we believed that considerable improvement followed the infusion of from fifteen to twenty ounces of such an alkaline solution (Cannon). Bayliss, however, states that in his opinion alkaline injections are not called for, and that whatever benefit may have followed their use might have been equally well due to the amount of fluid introduced.

Shock and Operation.—One of the most distressful features of work in a Casualty Clearing Station is the baneful influence which operative interference has upon men who are either already shocked, or who are on the border-line of shock.

A man is admitted in moderate condition, and one imagines that his chances of recovery are, at any rate, fair. Some operative interference is necessary, and it involves the administration of an anaesthetic. It may be during the anaesthesia—it certainly will be shortly afterwards—that the disastrous effects become apparent. There is profuse sweating, the pulse rate markedly increases, and so does the respiration rate. The most characteristic feature is the fall in blood pressure. During the progress of the operation, and while the patient is under the influence of the anaesthetic, a condition very closely resemblant

to surgical shock has been induced. If the symptoms are severe and in the absence of appropriate treatment, they may rapidly become fatal. There is restlessness, the pulse becomes uncountable and, at the wrist, imperceptible; the respiration rate continues to increase and the blood pressure continues to fall; death very rapidly ensues. This may be the experience with a case which is already in poor condition, and here one to some extent expects such an aggravation of symptoms, but unfortunately the complication often appears in those cases which at first seemed to be promising, and such are among the most bitter disappointments of this class of surgical work.

It is obvious that during the course of the operation and of the anaesthesia certain conditions are induced, or, if already present, are aggravated to such an extent as to bring out the train of symptoms we have mentioned.

What are the noxious conditions at fault? In this relation we must pay a tribute to the work which Prof. W. B. Cannon of Harvard University has done in throwing light upon the problem.

Examination before and after the operation shows certain features: (1) A post-operative lowering of the systolic and diastolic blood pressures; and it may be taken as a working rule that the seriousness of the patient's condition is in relation to the degree of the fall of blood pressure—the greater the fall in blood pressure, the more serious the patient's condition. (2) The blood examined with the haematocrit may show some degree of concentration at the end of operation, and it is likely that this is in relation to a loss of fluid by sweating; there is a relative proportional increase of the solid constituents of the blood. (3) Examination of the blood by Van Slykes' apparatus before and after operation shows a reduction of alkali, or, expressed in another way, it shows a development of acidosis.

These three factors are a counterpart of the changes which we described as occurring in wound shock, and it establishes

the truth of the statement that one has really reproduced during operation a condition of shock.

While these are the most striking demonstrable factors, there are certain related conditions, each of which plays some part in forming the ultimate clinical features. The first of these is the man's general condition before operation: a patient who is weakened by exposure, by haemorrhage, and by sepsis is peculiarly liable to that which we may term "operative shock." The second influencing feature is the extent and duration of the operation; a long operation and one associated with much traumatism is unpromising. An operation for multiple wounds —each wound perhaps slight in itself—often has a disastrous effect. A third, and an exceedingly important factor, is the influence of the anaesthetic: the contra-indications of the use of chloroform in septic cases have long been known, and experience in war surgery confirms the observation. Ether, while less deleterious than chloroform, has none the less a bad effect.

Professor Cannon has repeatedly demonstrated the marked increase of acidosis which often occurs after even a short ether anaesthesia. With gas and oxygen anaesthesia, these deleterious effects are reduced, if not averted.

Treatment of "Operative Shock."—We have spoken of operative shock from the pathological and from the etiological standpoints: it remains to discuss the methods by which operative shock may be averted; and, when established, the methods by which it may be counteracted.

Preventive Measures.—These may be very simply summarised:

1. If possible, delay operation on a case which shows persistent low blood pressure until means have been taken to raise the blood pressure.

2. Let the operative procedure be as short as possible consistent with thoroughness.

3. The operation should be carried out with the least possible interference and trauma: every effort should be made to avoid unnecessary loss of blood.

4. Avoid "chilling" of the patient before, during, or after the operation.

5. If it is possible to exercise a choice of anæsthetic, that choice ought to be given to nitrous oxide and oxygen.

6. If simple restorative measures have failed to raise the blood pressure before operation, the pressure ought to be raised artificially by the intravenous infusion of human blood (600 to 700 c.c.), or of a pint of 6 per cent gum acacia solution.

7. If examination of the blood shows that a condition of acidosis is present before operation—and this ought to be suspected if the blood pressure remains persistently low—a reserve of alkali should be built up by the intravenous infusion of one pint of 4 per cent sodium bicarbonate solution.

Active Measures.—When a condition of operative shock has been definitely established, means must be attempted to counteract it, but these measures are less satisfactory than preventive treatment, and therefore every effort should be made to prefer the preventive line. After the operation the patient is kept thoroughly warm. If the conditions are suitable, quantities of alkaline fluid are given by mouth, and there are advantages in combining sugar in the shape of glucose with the alkali. The giving of alkalis by the mouth in this way will often counteract a developing acidosis. If these measures are failing and the shock condition is deepening, recourse should be had to intravenous infusions. If there is evidence of an acidosis being present—and quickening of the respiratory rate is extremely suggestive of this—the 4 per cent sodium bicarbonate solution should be infused to the amount of 1 pint; if there has been an associated loss of blood an effort should be made to restore its volume by the transfusion of human blood, or by the infusion of 15 to 20 oz. of the colloidal solution of gum acacia.

CHAPTER III

GENERAL WOUNDS AND THEIR TREATMENT

It will avoid future error if we state what we mean by the term "general wounds," and the definition we offer is this: "Wounds of the soft parts not involving any visceral tissue or bone."

These wounds form a most instructive study of the action of the various projectiles used in war on human tissues ; and the various types of projectiles which conceivably may cause wounds are numerous.

Types of Projectiles.—*Bullets.*—There are a great variety of bullets in use in the present war, and apparently their number goes on increasing. The standard British, French, and German bullet is a pointed one.

The instability of a bullet is said to be most marked at the beginning and the end of the flight, and the German bullet in the first 800 yards or thereabouts of its course is peculiarly unstable. The velocity and stability of a bullet is largely affected by passing through sandbags or parapets, or when it is deformed and deflected by striking against hard objects.

Shell Fragments.—These are of course of all kinds, but the fragments causing wounds which the surgeon is called upon to treat are generally not more than $1\frac{1}{2}$ inches in the greatest diameter—usually a good deal smaller. Some importance may

be attached to the nature of the shell by which the man has been wounded.

High Explosive Shells.—These shells may burst in the air, on contact with the ground, or after they have embedded themselves deeply in the earth.

The velocity of the fragments into which the shell is disrupted depends upon the exploding charge, and the fragments fly out in all directions.

The shape of the fragments depends largely on the type

FIG. 1.—Various types of rifle bullets.
(1) British bullet; (2) French bullet; (3) German bullet.

of shell; if the shell is segmented the pieces are generally quadrilateral, otherwise while they are still roughly quadrilateral in shape they have extremely sharp and ragged edges.

Shrapnel.—These shells usually are timed to burst in the air. They are of all sizes, and the metal bullets with which they are filled also vary in size. The penetrating power of the contents is due to the remaining velocity of the shell, and their direction therefore will as a rule be downwards. In some cases a shell is of a combined high explosive and shrapnel type.

Bombs and Grenades.—In the early part of the war the bombs used were mainly extemporised : tin boxes were filled with explosive, scrap iron, nails and screws. Nowadays the case is made of grooved iron so that on explosion it breaks up into numerous quadrilateral fragments. Sometimes the force of the explosion will cause a bomb to burst into small

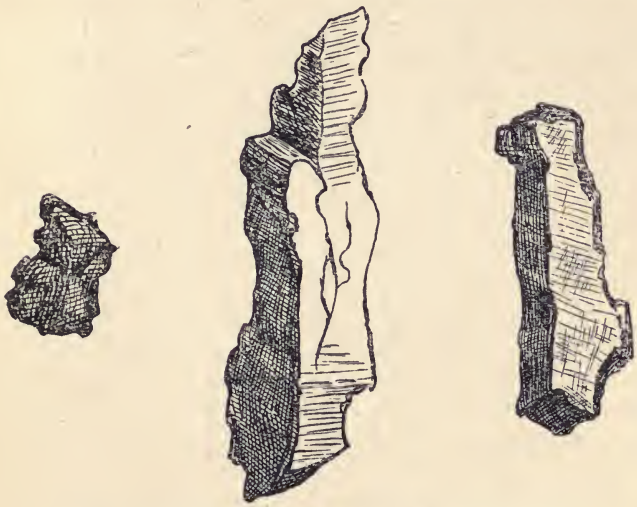


FIG. 2.—Various types of fragments of high explosive shell.

fragments often no bigger than a match-head. These fragments possess great penetrating power in the neighbourhood of the explosion, but this impetus is largely lost as the distance increases.

Trench Mortars.—The projectiles thrown by these are bombs of varying shapes and sizes. The explosive charge is contained within a thin envelope, and they therefore burst into thin sharp-edged fragments of varying size.

These bombs are generally timed to burst in or on the ground.

The Classification of General Wounds.—One may group wounds of the soft tissues in various ways. They may be classified on an etiological basis according to the projectile or weapon which caused the injury. This classification may be of interest from a statistical point of view, and undoubtedly it is so, but from the clinical point of view it is insufficient and does not carry with it enough descriptive element. Secondly, one may classify these wounds from the anatomical standpoint, and probably one of the most collective groupings is as follows:—

1. Perforating Wounds.
2. Penetrating Wounds.
3. Lacerated and contused Wounds.
4. Gutter Wounds.

Any weapon or projectile may conceivably cause any of the above-mentioned wounds, but certain provisional statements may be made. A perforating wound is most commonly the result of a rifle bullet travelling at a high velocity. Lacerated and contused wounds generally arise from the irregular-shaped fragments of shell or bomb. Gutter wounds may result from any projectile, and they depend upon the tangential relationship of the tissue and the projectile.

Infection of Wounds.—Generally speaking, there are infected and non-infected wounds. Unfortunately under war conditions the second variety may be assumed to form an exceedingly small proportion of the whole; in other words, the very great majority of war wounds are infected wounds.

One naturally asks oneself the question, is the infection primary or secondary—that is to say, is the infection carried into the wound either by the projectile and by whatever foreign material may be associated with the projectile, or is the infection sustained at some period later than the infliction of the wound?

It is probably correct to say that in the great majority of

cases the infection is primary. It was thought that by modern methods of antisepsis and first-aid dressings combined with high velocity projectiles, primary infection would have been reduced to a minimum; unfortunately this has proved not to be so, and therefore it has become necessary to readjust one's ideas on the subject.

From this point of view an exceedingly important factor to be taken into consideration is, that much of the fighting is being done over highly cultivated land which has been extensively fertilised for many years. We know that such soil is the habitat of large numbers of pyogenic organisms, and therefore it cannot be thought strange that men who are fighting on such ground, and whose clothing and even skins are often covered with this highly infected soil, should become readily and severely infected when wounded.

The Prevalence of various Micro-organisms.—In the field of wound bacteriology a large amount of work has been done to determine the various organisms which are most commonly present in wounds.

Fleming[1] has shown that the streptococcus is the most prevalent of the pus-producing organisms, and the staphylococcus comes next in frequency; he makes the reservation that the staphylococcus is probably infected from the skin surrounding the wound rather than from the projectile or foreign matter. Of the streptococci the haemolytic variety is the most dangerous.

Bacillus aerogenes capsulatus occurred in about 80 per cent of wounds which were not more than seven days old. In older wounds the percentage of its occurrence fell. In wounds from eight to twenty days old this organism was found in 34 per cent of the cases; while in wounds more than twenty days old the percentage of occurrence was about 18 per cent.

During the first twenty days of the wound's history he

[1] *Lancet*, Sept. 18, 1915.

found tetanus bacilli present in a small proportion. Coliform bacilli were common and tended to persist in the wound: various odd types of putrefactive bacilli, of diphtheroid bacilli, and of large-gram positive bacilli were found at various times. Fleming showed that there are two pathogenic organisms pre-eminently present in war wounds, and these are the Bacillus aerogenes capsulatus and the streptococcus.

Henry[1] divides the anaerobes found in wounds into two main groups, the Saccharolytic and the Proteolytic, and he believes that a recognition of such a classification, founded as it is on the basis of his chemical activities, is of considerable service in establishing the role played by anaerobes in the tissues.

The Saccharolytic group, which gives fermentative reaction in the presence of various carbohydrates, but which shows little tendency to attack proteins, comprises:

1. B. Welchii.
2. B. tertius.
3. B. fallax.
4. B. aerofetidus.
5. B. oedematicus.

The Proteolytic group develops vigorous digestive action towards protein material, while their carbohydrate splitting capacity is of limited power. The group contains:

1. B. sporogenes.
2. B. histolyticus.
3. B. putreficus coli.
4. B. tetani.

From the systematic investigation of 100 open wounds of varying severity, Henry found that two-thirds of these wounds contained B. Welchii, about one-half showed B. sporogenes, and about a quarter contained B. tertius.

[1] Henry, *Journ. of Path. and Bact.* vol. xxi. No. 3, p. 344.

Of the pyogenic infections we have said that the streptococcus is the type most frequently present, and of the different varieties of streptococcus the Streptococcus faecalis appears to be the most common. Other forms of streptococci are found, as are also the staphylococcus, Bacillus pyocyaneus, and the colon bacillus.

Wounds infected by pyogenic organisms do not show the severe local and constitutional effects which are seen in wounds contaminated by anaerobic bacilli, and the virulence does not appear to be so severe as are the infections from the same organisms which are seen in civil practice: the explanation of this last probably lies in the fact that the organisms have not attained a high degree of virulence by transmission from one human host to another. It is in the later history of the case that the pus-producing organisms become such an important factor.

Character of the Wounds.—The type of rifle bullet wound which was so commonly seen in South Africa, characterised by tiny wounds of entrance and exit, is rarely seen in the present war; even if the entrance wound be small, as it commonly is, the exit wound is almost always large and gaping. Constantly one finds that a rifle bullet has torn the soft tissues to pieces, and blown out muscles and fascia through great rents in the skin. The excessive destruction which one so constantly sees may have varying explanations: the discharge of the bullet at close quarters produces these destructive wounds. The German bullet has a muzzle velocity of approximately 1000 yards per second. In the first 800 yards or thereabouts the flight of the bullet is not steady but wobbling. There are three movements —a movement forward along the line of flight; a rotatory movement, in which the bullet spins round on its longitudinal axis, as a result of the rifling of the barrel; and a third movement, a "mouvement de bascule" as the French call it, of such a character that while the point of the bullet keeps steady,

the base of the bullet is moving round a circle or an ellipse of a gradually diminishing size. The result of this last form of movement is that when the bullet impinges upon any substance, even the clothing or the flesh, the infinitely brief arrest of the point which strikes first, allows the base, which is of course much heavier, to overtake the apex, and the bullet then lies

Fig. 3.—Wound of ankle caused by the lateral impact of a bullet.

sidewise or begins to turn over and over as it ploughs its way through the soft parts. When a bone is struck the damage is very great, for the bullet imparts its momentum to the shattered fragments and they are driven in every direction. A rifle bullet may enter the tissue on its proper axis, but immediately turns, and by so doing offers a much wider and destructive surface. We have seen an instance in which both lower limbs were perforated by the same bullet. The entrance and exit wounds on one limb were comparatively small, but the other

limb showed large gaping wounds, indicating that in the second instance the projectile had hit the limb sideways. Occasionally bullets make marks upon the skin showing that they have hit the part side-on.

Any break in the continuity of the hard envelope of the bullet which may release the lead core will of necessity produce disruptive wounds.

Shrapnel bullet wounds are generally characterised by large round wounds of entrance; their divulsive and explosive effects are not nearly so intense as in the case of the rifle bullet. One constantly finds that shrapnel bullets are retained in the tissues. All these peculiarities depend upon the fact that the momentum of shrapnel bullets is never very great.

Wounds caused by fragments of high explosive shell and by fragments of bomb and grenade are so infinitely various that it is impossible to describe any single one as typical. The fragments of metal being rough and irregular, the wounds which they produce are always lacerated wounds.

Whole areas of skin and soft parts may be torn away entirely. The tissues of the wound are crushed and lacerated, and there are widespread contusion and effusion of blood into the surrounding parts. The neighbouring blood-vessels are often pulped and thrombosed, and as a result of the interference with the blood supply whole areas of tissue may afterwards die and slough away. In these wounds, muscle appears to be affected more than any other tissue: it becomes a mass of dark brown crushed matter without any evidence of striation or vitality.

One cannot fail to be impressed by the enormous destruction which even a small fragment of shell will produce, a degree of destruction which is apparently quite out of keeping with the size of the fragment: the exaggerated damage depends upon the enormous velocity at which the fragments are travelling.

Bombs and grenades are particularly liable to cause multiple wounds: they generally burst close to the object, breaking up into a number of fragments of varying size. Some of the fragments may be exceedingly minute, yet they may penetrate to a great depth. One constantly meets with perforation of lungs or abdominal viscera wounded through an aperture so small that sometimes it is difficult even to see.

Fig. 4.—Gutter wound of upper arm.

These fragments have a high initial velocity, but being small in mass do not possess great momentum. Unless the burst has occurred at close quarters the wounds which they produce are slight ones.

The Pathology of Gunshot Wounds. — To understand the pathology of gunshot wounds one must bear in mind the fact that these wounds are produced by fragments of metal travelling at an enormous velocity. The injuries which these fragments produce are of a divulsive and expanding nature, and the damage produced is intensified by the resistance of the tissues to the explosive effect. The result is that the injuries are not limited to the immediate track of the projectile, but are diffused in every direction and through all the neighbouring structures.

If a structure is enclosed within a sheath, for example a

muscle, and this structure lies in the path of the entering projectile, the explosive effect upon such a localised structure is especially marked—the explosive force is magnified by the incompressibility of the encapsulated structure.

The missile may not only shatter the tissues in the line of its flight, but its divulsive force separates the fascia from the skin, separates muscles from each other, and produces ruptured blood-vessels and extravasations of blood some distance from the obvious track of the missile.

Morbid Anatomy.—The gross pathology is that common to all wounds—that is to say, there is a breach of continuity of all tissues through which the missile has passed. The skin appearances vary from punctured wounds of entrance and exit to large and gaping areas. Retraction of the divided skin exaggerates the apparent size; the skin edges approximating on the wound are generally devitalised and necrotic. There is a separation of the skin from the underlying tissues for a varying area surrounding the wound, and there are hæmorrhages of different degrees in the subcutaneous tissues. The condition of the deep fascia varies within wide limits—the wounds of entrance and exit in it may be small and buttonhole-like in appearance, at other times the fascia is torn to ribbons and lies on the surface in semi-detached strips. It is sometimes stated that the appearance of the wound in the deep fascia will give one a clue to the extent of damage of the underlying tissues and muscles—a small fascial wound is unlikely to be accompanied by much destruction of the underlying muscles. This is generally true, but one sees instances in which there are small entrance and exit wounds in the fascia, and yet the related muscles are pulped and disintegrated.

The soft and fragile muscle suffers more than any other tissue; it is rarely that one finds a single break in its continuity: it is generally shattered and divulsed, and often it looks as though it had been crushed to an unrecognisable pulp.

The blood-vessels are torn, and, as a rule, all vessels in the actual wake of the wound are thrombosed.

There is another point in the pathology which it is important to bring out. Many wounds show a small point of entrance and yet there is extensive separation and tearing of the subcutaneous tissues. This consideration is important from the point of view of treatment.

Microscopic Pathology.—In coming to an estimate of the microscopic pathology, it is important to remember that the appearances should be judged before infection has had time to play any part: an organismal infection will very rapidly alter and disguise wound appearances.

Macnee and Stokes, who were probably among the first to work at this subject, pointed out that not only were there the direct evidences of traumatism along the line of the wound, but that at some distance from the wound there were evidences of injury and disintegration. At varying distances from the wound they found rents tearing across several bundles of muscle fibres, the ends of the muscle fibres showing necrosis, and the rent itself being filled up with blood clot.

Bashford, who has more recently investigated this problem, discredits "distant" effects.

In discussing wounds of the subcutaneous tissues and aponeurosis, he says: ". . . here also the disturbance is limited to an area immediately surrounding the track of the missile"; and again, in talking of wounds involving the muscles, he says: "In them the sharpness of the margin of injury is most striking . . . the injury might be no less had it been produced by a knife."

He concludes as follows: "Although the obvious local effects of gunshot wounds may sometimes be surprisingly extensive in their ragged ramifications, the foregoing observations show that remote and other far-reaching effects are by no means universal. Indeed during eight months of close attention to

so important a subject, I have failed to find any evidence that they occur at all in the tissues or organs examined. If vibration be set up by the projectile in the tissues of the body, it does not result in capillary haemorrhages except in situations where they would be expected—for example, under the capsule of the kidney; and remarkable disintegration of cells—or even injury of any sort at a considerable distance from the obvious site of the injury, have not been met with."

It is probably correct to say that sections cut tend to show that there is not great molecular disturbance at any distance from a wound track, though blood effusion may extend away from it.

The Clinical Features of Gunshot Wounds.—Various impressions have been given of the sensation which a man sustains when he is wounded.

An officer of the most acute intelligence once described to us his impressions. He was passing by the side of a shell hole full of water when he suddenly felt that his right hip had been scalded. His first idea was that hot water had splashed from the shell hole and had fallen upon and burnt his hip. He did not realise he was wounded until he actually saw blood upon his breeches.

In this case, a machine-gun bullet had passed through the right hip from front to back without injuring the bone, but with a wound of exit the size of a man's closed fist.

Others will tell you that the sensation is one of an intense numbing blow; while one occasionally meets with men who will tell you that they experienced only the slightest possible discomfort, as though they had been flicked lightly with a stick or cane.

In the absence of a broken bone, wounds in their early stages are not generally very painful. It would seem as though the concussion of the tissues by the projectile had produced a dulling effect upon the conductivity of the nerves, and this

effect generally lasts for several hours. When it has passed off, a burning pain becomes a constant and distressing feature. With the establishment of infection the discomfort of the wound increases, and the development of effusion and oedema aggravates and intensifies the pain.

Any one who has had an opportunity of observing a large number of wounds cannot fail to be impressed by the comparative rarity of haemorrhage in any severity. Even in wounds of great extent it is uncommon to find arterial bleeding occurring: one constantly meets with wounds involving even the largest arteries, and yet there has been little or no bleeding. Venous bleeding is more common, and a steady capillary ooze is a constant feature. This last, by its cumulative effect, may become an ominous factor of very great importance. In many cases an alarming and even fatal amount of blood has been lost by an unarrested capillary oozing from a large wound surface.

There are probably two factors which account for the spontaneous arrest of arterial haemorrhage: one is the crushing and lacerating effect of the projectile in blocking up and obliterating the open mouths of the vessels; the other is probably a sudden lowering of the blood pressure, which occurs in relation to the sustaining of the wound.

When infection becomes established, as of course it does in the great proportion of wounds, a train of clinical features arise which are dependent upon the developing organisms.

The pain becomes altered and accentuated, the temperature rises, and there are the general concomitants of fever in the shape of thirst, malaise, etc. The character of the wound changes, the appearance depending to some extent upon the type of organism which is predominant in the infection. Certain areas of the wound which are devitalised will slough, and the characteristic discharge of an infected wound makes its appearance. In all infected wounds, and especially in deep

pocketed wounds, and in wounds with a retained foreign body, there is always the danger of a serious haemorrhage occurring from a sloughing of the walls of the blood-vessels. It may have been that the vessel walls were traumatised by the original missile causing the wound, or it may have been that the vessel walls were eroded by the tryptic ferments which are found in conjunction with pyogenic organisms.

Treatment.—*Primary Wound Disinfection.*—We have said that the great majority of war wounds are *ab initio* infected wounds. The question has been repeatedly raised whether something could not be done when the wound is first seen, which would either abort the infection entirely or at least would diminish and localise it. Up to the present no procedure has been adopted which fulfils the desired effects. The difficulty has been in introducing any antiseptic into all the ramifications of the wound, and it is in the deepest and most inaccessible pockets of the wound that infected foreign bodies are retained and that infection most frequently begins. Complete opening up of the wound would of course give the necessary access, but this is a procedure which is neither desirable nor possible in Regimental Aid Posts or Dressing Stations.

The present attitude is that deep antiseptic applications to the wound before the Casualty Clearing Station is reached are quite useless. The best procedure is to clean the skin as much as possible, removing all gross contamination from the surface, and to get the wounded man as quickly as possible to the Casualty Clearing Station.

Every effort should be made to prevent the wound from receiving any further infection. For the extensive and multiple wounds one or more of the larger shell dressings ought to be applied. Any obvious gross contamination of the wound should be removed when the wound is first seen, but any extensive exploration of the wound at this early stage is inadvisable.

It is now almost a general rule that if the wound is of any severity the patient is evacuated directly from the Advanced Dressing Station to the Casualty Clearing Station.

Formerly this was not so, and as the wounded man passed back through the various branches of the medical organisation to the Casualty Clearing Station, it was commonly found that his wounds were dressed at each stage of his journey. Unless complications arise sufficient to produce a necessity, it is unwise to disturb the original dressing—repeated dressing increases the danger of additional wound infection, and there is really nothing to be gained by it.

An occasional inspection of the applied dressing is all that is required, and such an inspection will very quickly reveal any complication, if such has developed.

Treatment at the Casualty Clearing Station.—It may be accepted as a working rule that a large proportion of gunshot wounds on arrival at the Casualty Clearing Station require operative interference of some description. There are a certain number in which operation is neither necessary nor desirable, and these are generally rifle bullet wounds with small wounds of entrance and exit which have passed through the soft tissues without damaging bone or large blood-vessels, and without the complication of a retained foreign body. It has been estimated that a good Casualty Clearing Station will operate upon 50 per cent of the wounded admitted during "time of peace." With the aid of the method of "primary suture," which we shall presently describe, small wounds will receive much more attention than formerly, so that such cases after excision and suture of the wound can shortly return to duty. Wounds which require no operative interference are treated by the application of a moist antiseptic dressing. Any antiseptic is used which the medical attendant may prefer—for the past two and a half years we ourselves have employed eusol to the exclusion of all other antiseptics, and we have

had every reason to be satisfied with our choice. In such favourable cases the dressings are left undisturbed for forty-eight hours or even longer; and generally the healing process proceeds without interruption.

The reason that such a relatively large proportion of the wounds require operative interference depends upon the fact that the wounds are infected, and not only are they infected, but the actual wound tissues are in such a devitalised and bruised condition that they are especially liable to fall victim to an extension of the infection. This is the main reason why operative interference is so imperative, and one may say the universal reason. There are other indications which occur—such as injury to underlying and associated vessels and nerves; injuries to bones, joints, or related viscera.

It must be borne in mind that the great differences between war wounds and civil injuries are that the former are of the long seton type, that they are complicated by the presence of foreign bodies, and that the wound is accompanied by much destruction of the internal parts of the limb. This last is partly due to velocity imparted to bone fragments, and partly to tearing of muscle by a ragged-shaped body with consequent retraction of muscle fibres.

Varieties of Operative Interference.—And now the question comes to be, what direction is the operative interference to take? One may summarise the possible procedures as follows:

A. *One may completely excise the wound, wash the wound surface with a fluid antiseptic, and immediately suture the wound hoping to get healing by primary intention: it is possible that the washing with the antiseptic may even be omitted.*

B. *The wound may be completely excised. An antiseptic in the form of a "depôt"* [1] *antiseptic is rubbed into the walls of the wound or applied to the wound, and primary closure of the*

[1] That is, an antiseptic which will remain in the wound for a prolonged period, continually providing an antiseptic action.

wound, either partial or complete, is carried out. If for any reason immediate suture is impossible, "delayed primary suture," i.e. *in 24-72 hours, may be performed.*

C. *The wound is fully opened up and all its ramifications are followed out and explored. All foreign bodies and evidence of gross infection are removed, bruised and devitalised tissues are excised, an antiseptic application is made to the wound, and efficient drainage is established.*

D. *The wound is thoroughly opened up, all sources of infection are removed, efficient drainage is established, and the wound is treated in the method described by Wright.*

E. *The wound is treated as outlined in* C *and* D, *and intermittent irrigation is secured according to the technique described by Carrel.*

General Consideration of Methods.—Unquestionably the best methods are those of A and B—methods which may be included under the term "primary suture." They are becoming more and more widely employed, and in future war-surgery the great majority of wounds will be treated on these lines. Method C has already very largely given place to that of primary suture.

Method D (Wright's) is now rarely employed. Method E (Carrel) is still largely used.

Application of Methods.

Methods A and B.—*Primary Suture.*—These two may be considered together. At one time it was thought that wounds suitable for treatment by primary suture were very limited in number, but, as we have said, the method has gradually been extended until at the present time about 50 per cent of wounds admitted to the Casualty Clearing Station are treated on these lines. A table of results has recently been circulated among the British armies in France, showing the experience in

primary suture of wounds from May to December 1917. Various applications were made to the wounds—eusol, B.I.P.P., flavine, various coloured pastes, soap and saline—but it does not appear that any one application presents advantages over the others. The circular shows that during this period an attempt was made to close 50 per cent of the wounds received, and success was obtained in 70 per cent of the cases. These results apply to the so-called "peace" times, *i.e.* periods when no active operations of any magnitude are in progress.

When hard fighting is going on, time may not permit of such a wide application of the method; under such conditions it is advisable thoroughly to excise the wound, pack it lightly with gauze, and evacuate the patient to the Base in a day or two. On arrival at the Base, suture of the wound may be done. This method has been employed on a large scale by the French with every success: the French used ether in the disinfection of the wound.

Major Haycraft, R.A.M.C., has lately reported his experience of primary suture—in some 200 cases.

In 156 cases, after excision of the wound, he used a solution of soap.[1] In 44 of the cases the wound was washed with normal saline.

He found that 70 per cent of the cases healed by first intention, 21 per cent showed slight suppuration in the wound, while in 9 per cent the method failed and the wound broke down. The series includes cases of all kinds exclusive of head, chest, and abdominal wounds. The results of 70 cases of compound fracture were included.

Technique of Methods.—Success depends primarily on accurate localisation of all foreign bodies by X-ray. The surrounding skin is efficiently sterilised by any method of choice, and throughout the operation the strictest asepsis is observed.

[1] 1 part of Marseilles soap in water or pure Sapo Duris 1 in 40.

Ideally, the wound should be excised without opening into any part of its track. Unfortunately such an ideal is not always possible, and then the wound track is thoroughly opened up to its ultimate extent, the damaged tissues of its walls thoroughly excised, and all foreign bodies removed. The eventual success of the method, no matter what antiseptic is employed, will depend upon the degree of thoroughness with which this primary excision is carried out. All bleeding is arrested, and the wound is dried with spirit or with a solution of 1 per cent picric acid in spirit. In many cases on anatomical grounds such a thorough technique may be impossible, but this does not contra-indicate primary suture, provided the majority of infected tissues are cleared away. Such cases do not so often heal primarily, but the subsequent infection is as a rule slight, and they generally heal well after slight suppuration. Haycraft believes that it is important to close the wound even though it is obviously impossible to remove all infection. He holds that complete closure of the wound prevents the escape of tissue fluids, which are the most valuable natural antiseptics. This is very strikingly seen in those cases developing a severe local reaction after operation, which subsides in a few days. These are probably instances where so much infection has been left behind that the tissues have only just been able to overcome it.

When excision is completed the interior of the wound is washed out with soap, saline, or eusol, or some form of depôt antiseptic is thoroughly applied to the walls and interstices of the wound. The use of the depôt antiseptic is becoming much less common than formerly.

The wound is closed by the accurate apposition with catgut of muscles, so as to obliterate as much cavity as possible. The skin edges are united by interrupted silkworm-gut sutures. It will be found to be an advantage to thread the individual sutures upon small pieces of capillary rubber tubing which lie

over the wound edges, and it is always safe to establish at least one point of drainage throughout the length of the wound.

When tension on the skin is great, one or two incisions on either side of the wound down to the deep fascia will relieve it.

Cases, if possible, should be kept for ten days after operation before evacuation. When the question arises whether the wound is to be opened up or not after operation, considerable judgment is required. The clinical appearance of the patient is of more value than pulse and temperature. There are many wounds which after operation become red, swollen, and oedematous, and yet eventually heal well. If the wound is beginning to break down, fomentations are often of great value.

The Method of Tissue Staining.—A modification of the method of primary suture has been introduced, and the modification aims at adopting some means which will indicate how far beyond the confines of the wound one must go in order to remove all the devitalised tissue. A fixation of the wound tissue *in vivo* is carried out. Certain French workers have used a solution of commercial formalin (40 per cent) containing 10 per cent methylene blue. This solution is poured into the wound and left *in situ* for some minutes. All devitalised tissues are stained a deep blue colour, and when the wound is excised care is taken that the cut edge extends beyond the stained area. More recently Captain Wilson Hey [1] recommends staining of the wound before excision. At first he used a 1 per cent watery solution of methylene blue, and later a ½ per cent watery solution of brilliant green. After sterilisation of the skin every effort is made to cover the wound track or surface with a ½ per cent watery solution of brilliant green. In the case of a track this is done by injecting the dye through a metal or rubber tube of fine calibre, closed at one

[1] *B.M.J.*, Oct. 6, 1917, p. 445.

end like a Carrel's tube and perforated by very many of the finest holes, so as to act as a spray. At the distal end are two rather larger holes to permit freer exit of the fluid.

The staining solution is injected along the tube without force, so as to avoid opening up cellular planes. In the case of a surface wound, a syringe or gauze soaked in the dye is used. At least two minutes should elapse before the excess dye is wiped away. Haemorrhage prevents staining. The wound is then excised, using the stain as a guide: wide exposure and good visibility are essential for the removal of every particle of stained tissue. The excision proceeds systematically from the skin to the depths of the wound, and if a foreign body is present it is removed last, preferably enclosed in its enveloping tissues. Irremovable structures are cleaned, and dirty bone is gouged. Only dry swabs or swabs soaked in spirit are used, and a most scrupulous search for all bleeding points is essential. The wound is dried throughout with spirit or with 1 per cent picric acid in spirit.

Method C.—This method implies thorough exposure of the wound through all its ramifications: the application of an antiseptic to the wound, and the subsequent establishment of efficient drainage. In the earlier days of the present war this method was the favourite routine, but it was a very imperfect application of the method. The wound was rarely properly opened up, and it was thought sufficient drainage was established when one or more tightly-fitting large-bore drainage tubes had been introduced. The method implies a great deal more than this. It involves the most thorough exposure of every portion of the wound, the most scrupulous removal of every particle of infected or foreign matter, the removal of what is obviously devitalised or infected tissue, the application of some chosen antiseptic to every portion of the wound wall, and, finally, the establishment of a very free and multiple drainage. No attempt is made to close the wound, and the

cavity is loosely packed with gauze wrung out of some antiseptic solution.

Indications for.—There are certain clear indications for the use of the method. It involves less time in its accomplishment, and it is more nearly "fool proof" than either methods A or B, and therefore it may perhaps be recommended as the method of choice for the inexperienced operator. It may be applied to wounds which from extent or position are not readily amenable to methods A or B. It has its greatest application in dealing with wounds which are already extensively infected.

The aims of the method are to arrest the spread of the infection which is already present, to lessen and eventually to abolish the infection, and to produce a clean granulating wound, which at some future date may be closed by secondary sutures.

The indications for this method are now considered to be much less common than formerly. Many wounds which used to be treated by cleansing and efficient drainage are now closed by primary suture.

The method finds its greatest use during periods of severe fighting, when the number of casualties and limitation of time render primary suture difficult. If the technique has been careful and successful, secondary suture of the wound is done soon after the patient reaches the Base.

Method D.—This method is now very rarely employed, but as there are some who still believe in its efficacy, it may be described.

Wright believes that the basis of treatment of wounds which are already infected ought to be that of bringing the protective elements of the body—that is, the blood fluids and leucocytes—into application in the wound. The agents which he employs to obtain this effect he has called phylacagogic agents, and he confines himself to two—a lymphagogic agent, hypertonic saline, and a leucocytagogic agent, physiological saline solution.

He claims that hypertonic saline has certain very direct results when applied to a wound. In a 5 per cent solution it entirely prevents any growth of microbes in a wound, and even in a 2 per cent solution it materially inhibits any such growth. By its action on leucocytes it liberates trypsin ferment and favours auto-digestion, and coming into operation on the walls of the wound it promotes an outflow of fluid. The effect of these results is to produce a wound which is free from infection except for a few streptococci and staphylococci, and a wound which is clean because of the separation of its sloughs, the dispersion of the induration, and the disappearance of pus.

The treatment of the wound is introduced by the use of the hypertonic saline solution, and it is persisted in until the wound is clean and free from pus. When this result has been secured, physiological salt solution is substituted for the hypertonic solution; it induces an active emigration of leucocytes on to the surface of the wound, and the remaining infective elements are destroyed by phagocytosis.

Subsequently, and this step is guided by the knowledge derived from cover-glass preparations made from the wound surface, the wound is closed with secondary sutures.

Such is briefly an outline of the theoretical lines upon which Wright's method is based. Let us now see the details by which the plan may be practically applied.

Technique.—In the Clearing Station the wound receives special attention: it is thoroughly opened up; devitalised and obviously infected tissues are removed; the projectile and other foreign matter excised, and efficient drainage procured. The wound itself is treated with hypertonic saline solution (5 per cent sodium chloride and 0·5 per cent sodium citrate). The wound is thoroughly syringed with the solution, and some of it is left *in situ*.

Strips of sterilised bandage steeped in the solution are introduced into the depths of the wound, and the free ends

carried out from the wound to be inserted between plies of lint well soaked in the same solution and folded over so as to form a thick pad. Finally, one or two tabloids of salt ought to be placed in between the back layers of the pad, and over the top of all ought to come a layer of impervious protective tissue. In the case of "gouged-out" or "punched-in" wounds of soft tissues, the strips of bandage would of course be dispensed with.

As regards the strength of the saline solution employed, 5 per cent is the most satisfactory solution—with sloughing wounds a 10 per cent solution may be applied, but this strength should not be exceeded. The skin surrounding the wound should be protected by a thin layer of vaseline, and when solid tabloids of salt are being used, care must be taken that they do not come into contact with the wound surfaces, otherwise an escharotic effect will be produced.

The action of the citrate of soda is for the purpose of preventing the lymph coagulating in the siphon bandages and on the walls of the wound. It may be omitted from the solution, which is used simply to irrigate the wound. The hypertonic solution is continued until the wound is free from sloughs and the infection is confined to the wound surfaces.

The physiological saline solution is now substituted, and irrigation with it is continued until the surface infection is extinguished or all but extinguished.

Wright recommends that if subsequent secondary suture of the wound becomes for any reason impracticable, Ringer's Solution or Locke's Solution (without the sugar) may be substituted. These solutions have a salt content more closely resembling that of blood, and are probably more favourable to the growth of connective tissue and epithelium; in other words, they are more suitable for a wound the closure of which is to be by granulation and not by secondary suture.

The theoretical bases of Wright's arguments have been

worked out as a number of most ingenious experiments—the clinical testimony varies: there are ardent supporters of the method and others who as strongly oppose it.

Indications for Method.—The experience has been that the method gives its best results when it is employed in wounds which come under efficient treatment at a stage rather later than is usual or proper; in other words, wounds in which sepsis is already well established and in which the walls show septic induration and sloughing.

Objections to Method.—Several objections to the method have been raised. There are patients who complain very bitterly of the pain when the 5 per cent solution is in use, and unless the skin is well protected there is a tendency for the surface to become excoriated and irritated. Wounds treated by the method have a tendency to become rather sluggish, and the later stages of healing are tedious and delayed. It has been stated that the method increases the liability to secondary haemorrhage on account of the rapidity with which sloughs separate. Our experience has been that the last statement has no very real basis.

Treatment by "Salt Pack" Method.—Mention must be made of the method of treating wounds by saline, devised by Colonel Gray,[1] in which sodium chloride is used in tablet or powder form. The method consists in first cleansing the wound thoroughly, then irrigating it with a 5 per cent salt solution, after which the cavity is packed loosely with gauze saturated with 5 per cent saline solution, and wrapped in the gauze are tablets of sodium chloride.

It is important that the gauze should be in contact with all the walls of the cavity, otherwise the treatment will not be efficacious. A rubber tube drain should be placed in the wound to assist in removing the fluids.

In this way one gets, owing to the sodium chloride being

[1] Gray, *British Medical Journal*, January 1, 1916.

able to absorb water, a constant hypertonic saline solution applied to the interior of the wound.

Hull's Salt Pack Method.—Another method has been described by Hull. It consists in making long narrow bags and filling them with salt. The bags are sterilised, and are inserted in the wound together with a small rubber drain; the outer ends of the gauze bags, which should be left long, act as capillary drains for the removal of the fluids.

It will be seen that the essential basis of treatment by saline solutions is that they promote a free flow of lymph and the active emigration of leucocytes, while they have a marked inhibitory power on bacterial growth and cause no coagulation of lymph.

Method E.—In the section dealing with antiseptics we discuss the antiseptic which is known as Dakin's Solution; at this stage we shall outline the method by which this solution or its modification is employed in wound treatment. (The Carrel-Dakin method.)

The method consists in the application to the wound, by a system of intermittent irrigation, of a solution of neutral sodium hypochlorite. The solution most commonly employed is the Daufresne-Dakin Solution.

It contains 0·45 to 0·5 per cent sodium hypochlorite, the causticity of which has been neutralised by adding the proper proportion of sodium bicarbonate and sodium carbonate. Owing to the bleaching powder being so unstable, the solution is titrated and tested at intervals for free caustic; it is kept in amber or flint glasses, and if stored in the dark the solution will keep with little appreciable alteration for about thirty to thirty-five days.

Before describing the application of the method, it is natural to ask the question, How does the solution act?

It is claimed that the application of the solution leads to the evolution of chlorine, the chlorine acts on the organic

matter present in the wound with the conversion of some of the NH. groups of the proteins into HCl. groups, producing new substances known as chloramins, which themselves are antiseptic.

Technique.—The first step in the method is the thorough opening up and cleansing of the wound. Foreign bodies and, as far as possible, all infected material are removed: obviously infected and devitalised tissue is cut away; all bleeding is most carefully arrested.

"The operation field is painted with tincture of iodine, and the bruised and necrotic skin-edges of the wound are trimmed away with a sharp knife. The knife and forceps are then put aside. With new instruments the wound is laid open like a book and gently explored for shell fragments, pieces of clothing, pockets, etc. Everything that could have been infected by the traumatism or could become the source of infection is removed. All non-infected tissues and tissues unlikely to become infected are preserved.

"Gentleness of manipulation is the keystone of the technic. Rough usage of the traumatised tissue is a technical crime.

"In many of the cases it will be found that fibres of clothing, dirt, grass, etc., are encrusted in the muscular surface of the wounds. To avoid overlooking this blood-stained debris, the tract of the projectile must be lightly but methodically resected. Great conservatism is exercised in the removal of comminuted fragments of bone.

"The same minute and careful mechanical cleansing is carried out in osseous wounds as in the soft parts. Before placing the instillation tubes a careful revision of the wound is made and particular attention paid to securing a perfect haemostasis. Muscular tissue infiltrated with blood is difficult to disinfect.

"There is another reason special to the employment of Dakin's solution which calls for a thorough haemostasis. Owing to its haemolytic property, Dakin's solution has the

property of dissolving recent blood clots; a poor haemostasis invites the danger of a secondary haemorrhage.

"Openings for drainage are rarely employed; if the necessity for their use should arise, one should avoid making them at

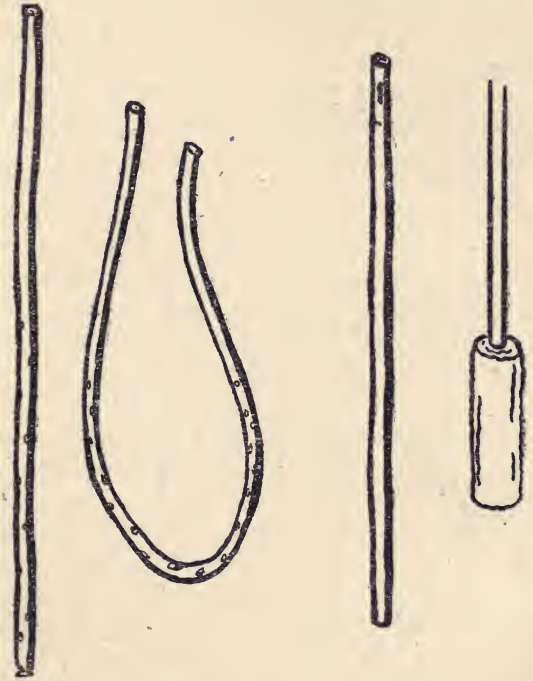


FIG. 5.—The various instillation tubes used in the Carrel technique. Nos. 1, 2, and 3 are simple perforated rubber tubes. No. 4 is provided with an envelope of turkish towelling, and is especially intended for use in superficial wounds.

the most dependent points, as the goal of technic is to keep the liquid in contact with all the surfaces of the wound.

"*The Introduction of the Instillation Tubes.*—The guiding principle is to place the tubes so that the liquid will come

into contact with every portion of the wound. The placing of the tubes will vary with the nature of the wound.

"*Superficial Wounds.*—A thin layer of gauze is placed over the wound, and on this the requisite number of instillation tubes. The tubes are secured to the wound edges by a rubber cuff and suture, or a two-way flow is used. If the tubes are placed directly on the surface they become encrusted and the orifices are blocked with granulations. Too thick a layer of gauze should not be used, as it will become clogged with the wound secretions, and prevent the solution from reaching the wound.

"*Penetrating Wounds.*—In the simple type, a tube without lateral perforations is introduced to the depth of the cavity and the solution allowed to well up from the bottom. In a large tract terminating in a cavity with irregular collapsible walls, a little gauze is introduced to support the walls of the cavity and allow a more thorough distribution of the fluid.

FIG. 6.—Glass ampoule of 1000 c.c. capacity.

Penetrating wounds with points of entrance in a dependent position (as the buttock, posterior surface of the extremities, and the back) are treated with perforated tubes dressed with towelling. These dressed tubes keep the antiseptic in contact with the wound. A suitable non-perforated tube can also be used.

"*Through-and-through Wounds.*—A perforated tube with the tied extremity uppermost is passed from the lower to the upper wound, the liquid, escaping through the small lateral holes, flows back along the tract to the inferior orifice moistening the entire wound. Wounds of the hand or foot, open

amputation stumps, etc., are immersed in Dakin's solution for from ten to fifteen minutes every two hours until the wound is sterilised." [1]

Necessary Materials for the Method.

1. A solution of 0·5 per cent sodium hypochlorite prepared by the Dakin and Daufresne technic.
2. A glass container with a capacity of from 500 to 1000 c.c.
3. Two yards of medium-sized rubber tubing.
4. An adjustable clamp for controlling the flow of the solution.
5. Rubber instillation tubes about 25 cms. long with assorted diameters (average size No. 16 French).

   These tubes are tied at the extremity and perforated with holes made with a punch. The primary and secondary tubes are 7 mm. in internal diameter, the final distributing tubes are 4 mm., and the little holes in these tubes are only 1 mm. (1/25th inch) in diameter.

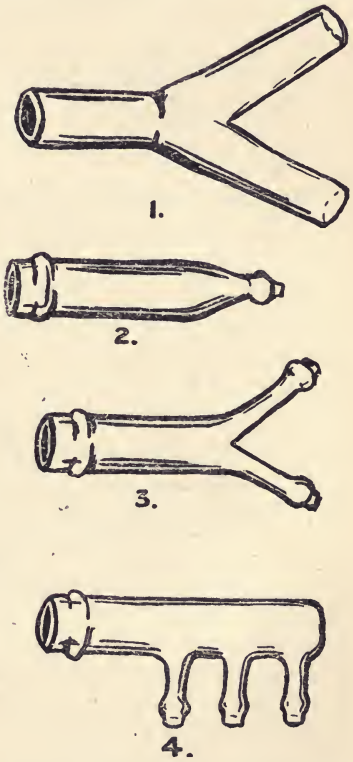


Fig. 7.—Various types of distributing tubes for use in the Carrel technique.

[1] Quoted from Lyle's paper in *Journ. Am. Med. Assoc.*, Jan. 13, 1917.

6. Ordinary rubber tube drains from 25 to 35 cm. long without lateral holes.
7. Glass connecting and distributing tubes.
8. The dressings consist of cotton surrounded by gauze.

   The cotton consists of a layer of absorbent cotton with a thicker layer of non-absorbent cotton. The dressings are about 3 cm. thick and of different sizes. Three different sizes are sufficient—one large enough to surround the leg once, a second to surround the arm, a third still smaller. Webbing straps with buckles fasten the dressing in place.
9. Sterilised piece of gauze impregnated with yellow vaseline to be used for the protection of the skin.

The After-care of the Wound.—The materials used are described above. In the care of the wound a strict instrumental technic is employed, the gloved hands never coming in contact with the wound or dressings.

Instillations of the fluid are made every two hours (day and night) by relaxing the adjustable clamp (for a second or two) controlling the flow. The amount of the solution employed varies with the nature and the extent of the wound; for the average wound 10 c.c. are sufficient. This interrupted instillation is kept up until the wound is proved sterile; the tubes are then removed, and a compress moistened with Dakin's solution is applied. Formerly a continuous instillation was the method of choice; if used at all it should be discontinued in from 24 to 48 hours. The rate of instillation is from 5 to 20 drops a minute according to condition. The object is to moisten the wound surfaces and not flood the bed.

Once a day—oftener if necessary—the wound, the tubes, and the flow of the liquid are inspected. Flushing the wound shows if the solution is being delivered as planned, and mechanically washes away the excess of wound secretion.

The Carrel method is not a continuous irrigation. It is a mechanical attempt to deliver an antiseptic of definite chemical concentration to every portion of a surgically prepared wound, and to ensure its constant contact for a prolonged period.

Systematic Bacteriologic Examination of the Wound.—This

FIG. 8.—Bed-foot provided with upright for attachment of ampoule.

consists in a regular determination of the number of microbes on the wound surfaces. It is done by transferring with a standard loop a portion of the secretion to a slide, staining the film, and counting the number of microbes per microscopic field. This is carried out every second day, and the results are entered on a suitable chart. When the microbes are absent

from the wound on three successive counts, the wound is considered sterile.

Though not absolute the bacteriologic count is of great practical value as a therapeutic guide.

It is better to begin the bacterial chart one or two days after the reception of the patient. As a rule, the germs begin to appear after the ninth or tenth hour. There is an

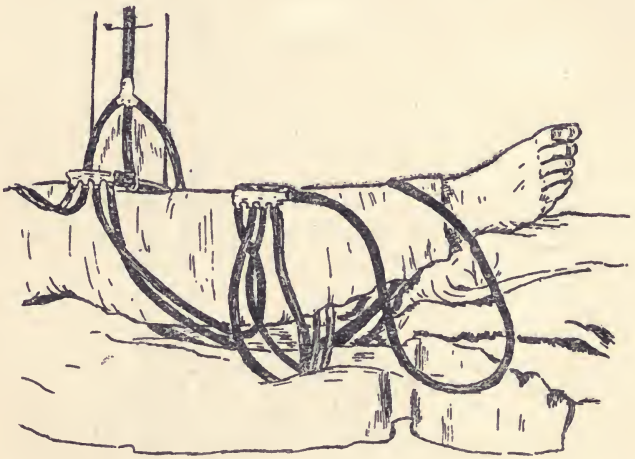


Fig. 9.—Scheme of distribution of fluid to an extensive wound of the calf.

initial rise on the second or third day. This remains so for a few days and then the descent begins. Wounds of the soft parts are sterilised in from five to eight days. Greatly traumatised wounds require a longer time. Fractures can be sterilised in from two to four weeks. If sequestra are present they must be removed to obtain an asepsis. Wounds sterilised by the Carrel method are readily reinfected if the treatment is stopped.

Closing the Wound.—Though the subsequent closure of the

wound is not often practicable in the Casualty Clearing Station, some points in regard to it may not be out of place here. If on three successive counts negative bacteriological readings are

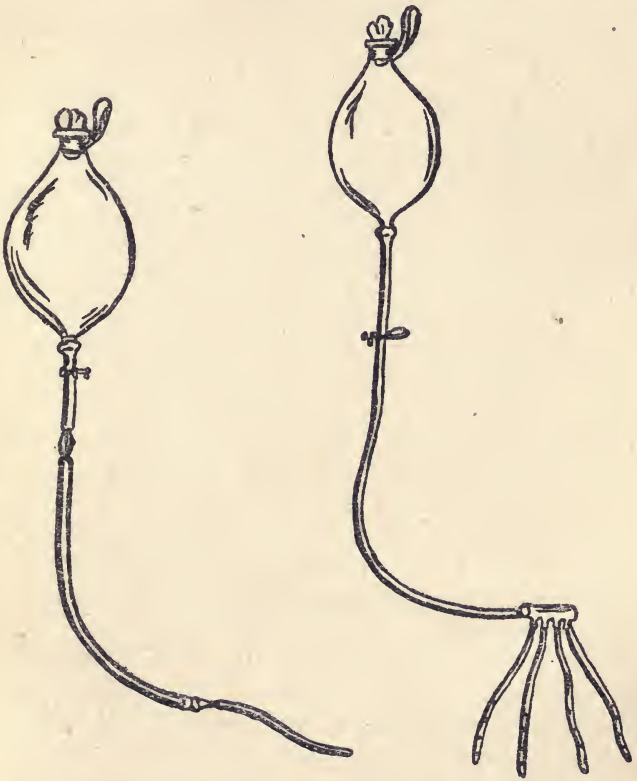


Fig. 10.—Glass ampoules provided with connecting and distributing tubes.

made, it may be assumed that the wound is sterile, and closure is proceeded with. In favourable cases this may be done on the fifth day; the average time in wounds of the soft parts is from seven to nine days.

Closure is carried out with careful layer sutures. In cases in which suture cannot be applied the wound is closed by adhesive strips which are applied along each side of the wound and laced together with elastic cord.

FIG. 11.—Secondary closure of wound edges by co-aptation with strips of sticking plaster.

For this purpose bands of Canton flannel are used ; they are made slightly longer than the wound, and the breadth is a little less than half the circumference of the limb. One edge of each is hemmed, and on the hemmed edges shoe hooks are inserted every 2 cm. The Canton flannel is secured to the limbs with a resin varnish or Heusner's glue —the woolly side of the flannel being put next the limb. When the strips are firmly adherent they are laced together with rubber bands—the tension of the rubber bands soon draws the wound edges together.

Further Details of the Technique.—To overcome the possible irritation of the skin by the solution the body surface for three or four inches around the wound is covered with gauze impregnated with sterile vaseline. Bandages of gauze (No. 4 mesh) $2\frac{1}{2}$ to 3 inches wide are cut in suitable lengths and placed in layers on trays. They are covered with melted liquid vaseline, placed in the autoclave and sterilised.

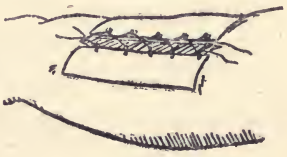


FIG. 12.—Secondary closure of wound edges by laced flannel strips.

The excess of vaseline is poured off and the trays are allowed to cool—each strip is peeled off as required.

At each dressing the surrounding skin edges are scrupulously cleaned : any excess of vaseline is removed with ether, the skin is cleansed with a neutral 8 per cent solution of sodium oleate ; this is followed by saline and ether to dry the skin surface.

When the rubber distributing tubes are being cleaned the terminal closing thread must be removed.

If Carrel's method is being used to any extent there are great advantages in having a dressing-carriage specially arranged for the technic. The following articles should have a place on it: Trays of perforated Carrel tubes, of plain Carrel tubes, and of tubes covered with turkish towelling; trays of vaseline gauze; sterile dressing forceps; haemostat forceps; scissors and scalpels; trays for soiled Carrel tubes and for soiled instruments; ether bottle; jar of small cotton sponges; jar of turkish towelling; bottles of sodium oleate solution, Dakin's solution, and physiological saline; jars for bandages; an irrigating bottle; and three small basins for Dakin's solution, for saline, and for sodium oleate respectively.

Disadvantages of the Method.—In spite of its value there are certain objections to the Carrel-Dakin treatment when the Dakin-Daufresne solution is employed.

1. A persistent and very painful irritation of the skin may arise. To minimise the risk of this occurring the skin must be protected by vaseline, and minute care must be taken to ensure the exact strength of the solution. Below 0·45 per cent the germicidal action is too feeble, above 0·50 per cent the solution is too irritating. This means that the solution must be most carefully made and tested as described in the chapter on antiseptics, and that fresh solution must be constantly prepared.

2. The solutions when in contact with wound exudates lose their chlorine in an hour or less, and thus become inert. Hence the need of a new supply every two hours.

3. In order to obtain the maximum germicidal effect of weak hypochlorite solutions it is necessary to keep them in constant contact with all surfaces of the wound. Both of the above-mentioned conditions imply constant care, the expense of much solution, apparatus, dressings, nursing and surgical staff.

We have described the Carrel-Dakin method when the Dakin-Daufresne solution is employed, but other antiseptic solutions may be used, being distributed to the wound in the same way. We have constantly used "Eusol" for this purpose, and this solution has many distinct advantages. Its preparation is easy; the fluid, on account of its neutrality, is non-irritating; it retains its germicidal action for a long period; and it has none of the corroding effects on rubber tubing which is such a drawback to the Dakin-Daufresne solution.

Solutions of the synthetic dyes have been used in a similar manner.

Treatment of Wounds by the Chloramin Method.—We have described elsewhere the preparation of Chloramin T. and Di-chloramin T. (see chapter on antiseptics). When the nascent chlorine of the hypochlorites comes in contact with the wound exudates a germicidal substance "Chloramin" is formed. Dakin introduced a synthetic Chloramin for use in the treatment of infected wounds. The first substance he produced was called Chloramin T. (toluene-sodium-sulpho-chloramide); this was found to be too irritating, and Di-chloramin T. (toluene-para-sulphon-dichloramin) was next produced. The substance can be bought on the market, and it may be applied to the wound in an aqueous or an oily solution.

The second method (an oily solution) gives the best results, and another additional advantage is that the dressings do not stick and the procedure is painless.

A useful method of preparing the solution is by dissolving 10 grm. of crystals of the Di-chloramin T. in 75 c.c. chlorinated eucalyptus oil and diluting the solution with equal parts of chlorinated paraffin oil.

The use of eucalyptus oil as a solvent has the disadvantages that it is expensive and difficult to procure, and that its use is sometimes followed by a rash.

For these reasons Dakin and Dunham now recommend a solvent prepared by the chlorination of paraffin wax to which they have given the name "Chlorcosane." It is a bland rather viscous oil which readily dissolves Di-chloramin T., and the solution so prepared is stable over long periods if kept under suitable conditions.

Method of Application.—The wound is cleaned and prepared in the way which has already been described. The solution is then applied as a spray by an ordinary hard rubber or all-glass atomiser. Metal should not be used, as the chlorine rapidly attacks it. Application is made to every part of the wound and really very little of the fluid is required. The solution is an active lymphagogue, and for a time the amount of wound secretion may be considerable; as granulation tissue appears the secretion lessens and the wound becomes dry. The germicidal action of the fluid continues for eighteen to twenty-four hours, and the dressing, therefore, is done only once a day. The technic is simple, and there is great saving of material and time.

CHAPTER IV

ANTISEPTICS

THERE are few subjects which have demanded more constant attention during the present war than the question of the treatment of infected wounds. The problem has proved more difficult than would have been surmised owing to the frequency, the malignancy, and the persistence of wound infection.

In civilian work modern wound treatment resolves itself into two groups—the aseptic treatment and the antiseptic treatment. The former of these, the aseptic treatment, has had until quite lately but a very limited sphere of usefulness in war; and the sheet anchor of wound treatment has been antiseptics.

In the chapter on general wound treatment we have shown how the pendulum is now beginning to swing in the opposite direction. More and more attention is being paid to the thorough mechanical cleansing of the wound under aseptic conditions, and we are learning to rely more fully upon the natural resistance of the body fluids to any residual infection.

A definite amount of any antiseptic has limited powers of disinfection in so far as these antiseptic powers are lost when combinations are formed with proteins and other compounds in the wound exudates. To this statement exception must be made in regard to the formation of those bodies which contain active chlorine united to nitrogen (chloramines); these are said to retain their germicidal action for a considerable period.

It is the limitation of the disinfecting power of an antiseptic which has led to the adoption of the methods of wound treatment by continuous or intermittent irrigation.

It is impossible and it is not desirable to give any detailed account of all the antiseptics which the present war has brought into prominence; only the more successful varieties and those which are representative of antiseptic groups will be discussed.

The Older Antiseptics.—As judged by the action on micro-organisms suspended in various media outside the body, the older antiseptics, such as carbolic and mercury, promised well in the campaign against wound infection, but the results have been disappointing. It became apparent that the most active germicidal substances *in vitro* were not necessarily so successful when employed *in vivo*, and the idea that dirty lacerated wounds could be sterilised by isolated applications of powerful antiseptics had early to be abandoned. It was realised that when complete sterilisation by this means was effected (and it very rarely was) the concomitant injury to living tissues by the unintelligent application of corrosive antiseptics might far outweigh any advantage gained.

Therefore, except as constituents of certain of the antiseptic pastes, the group which we have termed the older antiseptics have had only a limited application in the wound treatment of the present war.

There is one substance lately introduced which, though a derivative of the mercury salts, is said to possess none of the disadvantages of that group—this is the substance known as Mercurophen. A description of it will be found in a paper by Schomberg-Kohner and Raiziss in the *Journal of the American Medical Association* of May 19, 1917.

Mercurophen does not corrode metal instruments; it is said to be non-irritating and yet to be a far more powerful germicide than corrosive sublimate, carbolic acid, etc. Though so effective a germicide it is non-poisonous.

Hypertonic Salt Solution.—The method advocated by Sir Almroth Wright demands the employment of salt solutions of varying concentration. While the antiseptic properties of the solution play a considerable part in the treatment, Wright claims that the benefit is largely due to an increased lymph flow from the wound surfaces. The method has been fully discussed in the chapter on general wound treatment, as has also the so-called "Salt Pack Method."

The Hypochlorites. — Among the innumerable antiseptics which have been employed in the present war, two appear to have been regarded with especial favour. These are the calcium hypochlorite and boric acid mixture, introduced by Professor Lorrain Smith, Doctors Drennan, Rettie, and Campbell under the name of "Eusol," and the neutral sodium hypochlorite solution of Dakin.

The germicidal action of hypochlorites had been made use of in various departments of science, and the liquor sodae chlorinatae has long been a favourite in certain London hospitals. The solutions, however, had never come into general use as antiseptics, and the main reason for this was undoubtedly to be found in the fact that commercial hypochlorite preparations commonly contain free alkali, and hence are intensely irritating. The success of the above solutions depends on the extent to which the alkalinity has been reduced without impairing the efficiency of the antiseptic.

The Edinburgh Preparations, Eupad and Eusol.—In describing these preparations we shall quote largely from the paper by Lorrain Smith and his fellow-workers published in the *British Medical Journal*, July 24, 1915:

"The hypochlorites used mainly in the form of bleaching powder have been largely employed for sterilizing water supplies, but their use in general surgery as antiseptics has been very limited. It is an interesting fact that as far back as 1846 Semmelweis stamped out an epidemic of puerperal fever

in Vienna by the use of bleaching powder. . . . In our observations on the hypochlorites we found that hypochlorous acid is a more potent germicide than its salts, and we have accordingly devised a method in which the free acid is employed as the antiseptic agent.

"Pure hypochlorous acid in aqueous solution always contains free hydrochloric and chloric acids due to spontaneous decomposition. One molecule HClO is oxidised to $HClO_3$ at the expense of other two molecules which are reduced to HCl. Both are very strong acids and therefore pure hypochlorous acid is not suitable for wound treatment.

"The composition of Eusol may be represented by the following equations:

$$2CaOCl_2 + 4H_3BO_3 = 2HClO + CaO\ (B_2O_3)_2 + CaCl_2 + 5H_2O$$

the solution therefore contains free hypochlorous acid and calcium biborate. Calcium biborate is soluble in water and is an acid salt of extremely low hydrogen ion concentration. In the presence of this salt the free hypochlorous acid decomposes very slowly, the acids formed by the decomposition are at once taken up by the boric ions forming boric acid and calcium chloride. The acidity of the solution therefore cannot rise above the dissociation constant of boric acid which is very low.

"By virtue of this balance several advantages have been secured. The alkalinity of the bleaching powder, which had hitherto prevented its general application in surgery, has been eliminated, the full effect of the hypochlorous acid has been made available, and the solution cannot become unduly acid. It can therefore be applied freely to the tissues of the body."

Methods of Preparation.—The preparation of Eusol is extremely simple and requires no expert chemical knowledge. The ingredients are obtainable anywhere and are, moreover, very inexpensive.

To prepare Eupad, ordinary commercial bleaching powder

or chloride of lime is ground in a mortar to a fine powder, and then intimately mixed with an equal weight of boric acid powder. The mixture should be kept in closely stoppered bottles, and not exposed to light more than necessary.

Eusol may be prepared by two methods:

1. Twenty-five grammes of Eupad are shaken up with 1 litre of water, allowed to stand for a few hours, then filtered through cloth or filter paper.
2. To 1 litre of water add 12·5 grammes bleaching powder, shake vigorously, then add 12·5 grammes boric acid powder and shake again. Allow to stand for some hours, preferably over night, then filter off, and the clear solution is ready for use.

The solution contains:

Hypochlorous acid	0·26 per cent.
Calcium biborate	1·28 „
Calcium chloride	0·17 „

The hypochlorous acid is estimated by titration with N/10 arsenious acid solution; this method is better than the KI method as the presence of chlorates does not affect the result.

A concentration of 0·25 per cent hypochlorous acid has been found the most satisfactory. Stronger solutions may be prepared by this method, but no advantage is gained, as they rapidly lose strength, coming down to about 0·25 per cent free acid, after which they decompose more slowly; for practical purposes a solution of 0·25 per cent remains effective for from three weeks to a month.

The general conclusion from the clinical observations is that hypochlorous acid, both in solution and as a gas, has a high antiseptic value in surgical practice.

Since there is no danger of absorption of the antiseptic or its decomposition products the rule may be safely followed of applying the antiseptic in the strongest form consistent with the comfort of the patient.

Any bad effects that might arise are purely local in incidence, and therefore easily controlled.

Eusol (0·25 per cent HClO) has so far given no indication of deleterious action even on devitalised tissues, and may be used, therefore, with impunity in full strength.

Dakin's Solution.—Neutral hypochlorite solution prepared with boric acid is made as follows: 140 grms. of dry sodium carbonate Na_2CO_3) or 400 grains of the crystallised salt (washing soda) are dissolved in 12 litres of tap water, and 200 grms. of chloride of lime (chlorinated lime) of good quality are added. The mixture is well shaken, and after half an hour the clear liquid is siphoned off from the precipitate of calcium carbonate and filtered through a plug of cotton wool; 40 grms. of boric acid are added to the clean filtrate and the resulting solution is ready for use. A slight additional precipitate of calcium salts may slowly occur, but it is of no significance. The solution should not be kept longer than one week.

The boric acid must not be added to the mixture before filtering but afterwards. The solution should be tested for neutrality by adding to some of it a pinch of solid phenolphthalein. If a red colour indicating free alkali should develop, a little more boric acid must be added in order to remove it.

Daufresne's Technic.—Neutral hypochlorite prepared without boric acid is best made according to the formula given by Daufresne:

200 grms. of good bleaching powder are put in a bottle with 5 litres of tap water. The solution is shaken vigorously and allowed to stand for at least six hours. In another vessel 100 grms. of dry sodium carbonate and 80 grms. of sodium bicarbonate are dissolved in 5 litres of cold water and then added to the bleaching powder mixture.

The whole is shaken vigorously for a few minutes and the precipitate allowed to settle; at the end of thirty minutes the

clear solution is siphoned out and then filtered through paper. This solution must invariably be tested for neutrality by adding a pinch of solid phenolphthalein to a little of the solution. If the solution should react alkaline one of three methods must be employed to correct it:

(*a*) Pass CO_2 gas into the solution until a sample shows no alkalinity when tested.

(*b*) A neutral hypochlorite may be secured by reducing the proportion of carbonate of soda and increasing the bicarbonate.

(*c*) Boric acid may be added until neutrality is secured.

An advantage of the carbonate-bicarbonate preparation is that it possesses greater stability and can be left for several weeks without much deterioration. On the other hand, with the varying qualities of bleaching powder containing different amounts of free lime it is more difficult to adjust the proportions so as to obtain a neutral solution directly. For preparing the carbonate-bicarbonate solution laboratory facilities are required; the boric acid mixture is readily made under less favourable circumstances.

If it is desired to titrate the solution it is done as follows: Measure 10 c.c. of acetic acid, pour into the mixture a decinormal solution (2·48 per cent) of sodium thiosulphate (hyposulphite) until decoloration. Let N equal the number of cubic centimetres of thiosulphate employed. Then the quantity of sodium hypochlorite for 100 c.c. of the solution would be given by the equation

$$T = N + 0{\cdot}03725.$$

Sometimes it is necessary to titrate the chlorinated lime, the variation in the strength of the commercial products making it necessary to determine the amount of active chlorine in the bleaching powder.

The first step is to select an average sample. This is done by selecting small amounts from different parts of the jar:

Weigh 20 grm. of the selected powder and mix with 1 litre of water. Allow it to remain in contact for a few hours, then take 10 c.c. of the clear fluid, add to it 20 c.c. of a 10 per cent solution of potassium iodide and 2 c.c. of acetic or hydrochloric acid. To the resultant solution add a decinormal solution of sodium thiosulphate (2·48 per cent) until decoloration. The number N of cubic centimetres of this sulphate employed, multiplied by 1·775, will give the weight N of active chlorine contained in 100 grms. of chlorinated lime. The test is applied to every new sample of bleaching powder. If the sample contains more than 25 per cent of active chlorine, the proportion of the three chemicals in the formula must be decreased. That is, each of the three numbers, 200, 100, and 80, is multiplied by 25/N—N representing the weight of the active chlorine per cwt. of the bleaching powder.

Rosengarten's Method.—Rosengarten[1] has described a simplified method for the preparation of the solution employed in the Carrel-Dakin method of wound treatment.

Three things are necessary: a solution of chlorinated soda containing 2·8 per cent to 2·9 per cent available chlorine; an approximately 5 per cent aqueous solution of sodium bicarbonate; and a small quantity of phenolphthalein powder.

Dilute 1 volume of the chlorinated soda solution with 5 volumes of water, add 25 c.c. of the sodium bicarbonate solution for every litre of the chlorinated soda solution and mix well. Remove 20 c.c. of the mixture and add a small pinch of phenolphthalein and shake gently for two minutes. If no red colour appears the solution is ready for use. Should a red colour develop add 10 to 20 c.c. of sodium bicarbonate solution, mix well, and test again for free alkali with the phenolphthalein.

Meyer's Method.—Meyer[2] has published an account of a

[1] *Journ. Amer. Med. Assoc.* lxix. 13, p. 1075.
[2] *Paris Medical*, 1916, viii. p. 207.

magnesium hypochlorite solution for which he claims certain advantages.

Two solutions are made—the first contains magnesium sulphate 190 grms. and water 1 litre; the second is made by adding 100 grms. of bleaching powder to 2 litres of water.

The two solutions are mixed, a precipitate of calcium sulphate appearing; this is filtered off, the filtrate being a solution of magnesium hypochlorite.

The solution is said to be milder and less irritating than either sodium or calcium hypochlorite, while its germicidal properties are equal to those of the other solutions.

The Chloramines and Di-chloramines.—Chloramines are substances containing chlorine linked to nitrogen, almost all of which possess marked germicidal properties. Hitherto the most widely used member of this group was sodium-toluene-sulphochloramide, which is known under the name of Chloramin T. This substance is irritating and of less germicidal power than Di-chloramin T., and it is the last substance which is now employed.

It is unnecessary to describe the method of preparation of Di-chloramin T. The method is a complicated one, and can only be undertaken by an expert chemist in a well-equipped laboratory.

The substance is applied to the wound in a solution of chlorinated eucalyptol diluted with chlorinated paraffin oil—or in the new solvent chlorcosane.

Synthetic Dyes as Antiseptics.—Certain synthetic dyes possess a strong selective anti-bacterial action, and some excellent results have been obtained by the use of dyes of the triphenylmethane series.

Crystal violet, malachite green, and brilliant green have been those in most common use.

Fildes-Raychman and Cheatle[1] were among the first to

[1] *Lancet*, June 24, 1915.

apply the disinfecting action of these dyes to wound treatment; they used a mercury compound of malachite green sprayed on to the wound surface in alcoholic solution.

A brief note by Browning and Gilmour[1] drew attention to the bactericidal properties of brilliant green, and a number of investigators have since written of its advantages.

The dye is generally applied in a strength of 1 in 1000 as a solution in distilled water. It may be dissolved in normal saline or hypertonic saline without fear of precipitation. If dissolved in ordinary tap water a precipitate generally forms. Sometimes it is applied in an alcoholic solution.

After the wound has been cleaned and dried the solution is applied by a syringe or by gauze soaked in the fluid. The stain diffuses quickly over the surface of the wound, temporarily colouring everything a bright green. The wound is lightly packed with gauze dipped in the solution.

A recent publication by Browning[2] deals with the further development of the use of dyes as antiseptics. He worked with a dye of the acridine series, "trypaflavine" (diamina-methyl-acridinium chloride), and on account of its more general application he proposed to call it "flavine." Browning found that while the antiseptic action of all other substances examined, including several of the dyes, is greatly diminished by the presence of blood serum, that of flavine was not only not diminished but was conspicuously increased, even to five times its potency in water. This, taken in conjunction with Browning's further observations that flavine is harmless to the tissues and even to the activity of leucocytes, awakened great expectations concerning its therapeutic value.

These expectations have not been entirely realised. It happens with flavine, in common with the other synthetic dyes, that after a few days the diminution of sepsis in the wound

[1] *Journal of Path. and Bact.* vol. xviii. No. 1, p. 144.
[2] *B.M.J.*, Jan. 20, 1917.

ceases to be progressive, the granulations become pale and flabby, and the wound surface becomes covered with a gelatinous-looking pellicle.

The cause of the arrest has not been definitely determined: whether it be that the tissues are over-stimulated, or there has remained a strain of bacteria which have become resistant to the action of the dye, or the concentration of the substance is not suitable. If this objection arises it is overcome when another antiseptic is substituted—eusol, for example, removes the pellicle, and from this point healing is generally uninterrupted.

Antiseptic Pastes and Powders.—A large variety of antiseptic pastes and powders have been used at one time or another. One of the best known is Rutherford Morrison's B.I.P.P. It is a paste of iodoform and bismuth with a basis of liquid paraffin which is applied to the interior of a wound in order to act as a depôt antiseptic.

Its composition is as follows:

Bismuth . .	1 ounce.
Iodoform . .	2 ounces.
Liquid paraffin .	q.s.

When first used large quantities of Morrison's paste were frequently left *in situ* in the wound, with the result that undesirable constitutional effects due to absorption of the iodoform or of the bismuth began to be reported. This difficulty has been largely overcome by allowing only the smallest possible amount of the paste to remain in the wound.

In view of these undesirable constitutional effects Colonel C. J. Bond has begun to employ a paste of 1 part of acriflavine in 500 parts of stearate of soda soap.

While acriflavine used in this depôt manner does not seem to inhibit the growth of organisms or sterilise wounds as thoroughly as Morrison's paste (B.I.P.P.), it yet has a valuable antiseptic effect on stre tococcal and staphylococcal infections,

while its non-toxic character and transparency to X-rays are valuable points in its favour.

Captain Wilson Hey claims excellent results in primary disinfection with a paste the antiseptic basis of which is brilliant green; the paste is made as follows:

Boric acid . .	11 oz.
French chalk . .	1 oz.
Liquid paraffin . .	8 fl. oz.
Brilliant green . .	17½ grns.

In the composition the brilliant green has a strength of 1 in 500. The boric acid and the French chalk are intimately mixed in a mortar, the liquid paraffin is then worked in, and finally the brilliant green dissolved in rectified spirit.

CHAPTER V

GUNSHOT INJURIES OF BONES

THE scope of the present article is limited to a discussion of injuries to the long bones. It is not proposed to deal with injuries of the skull, the vertebral column, the carpus, or the tarsus, as these will be considered in connection with the nervous system or injuries to joints.

Physiological Considerations.—As introductory to and explanatory of some of the clinical features of gunshot injuries of the long bones, it is necessary to consider certain of the more important physiological features of healthy bone. The first of these is the question of the blood supply. The blood supply of a long bone is derived from three different sources: One or more nutrient vessels supply the medulla throughout the length of the shaft. At each articular extremity there are numerous vessels which enter the bone in relation to the reflection of the synovial membrane and the attachment of the capsular ligament of the joint—they are derived from an anastomosis around a neighbouring joint, and they anastomose with the termination of the nutrient vessels towards the articular end of the bone. A third group directly supply the articular ends of the bone—they are more in evidence in young growing bones with active epiphyses, and they are called the epiphyseal vessels. The vascular scheme is completed by a complex anastomosis beneath the periosteum.

We have given attention to the vascular supply because the abundance of it explains the rarity with which we find any widespread necrosis secondary to an infected fracture.

The other physiological point is in regard to the periosteum. Bone is simply connective tissue in which the intercellular tissue is calcified. It is surrounded by a capsule of connective tissue—the periosteum. Much debate has arisen regarding the bone-forming power of the periosteum. M'Ewan of Glasgow has denied that it possesses any such power, and at the present time the view generally held is that while the periosteum does not form bone, yet it greatly favours bone growth.

An essential for bone life and bone growth is the osteoblast. In the natural growth of the young bone, these cells become collected on the bone surface, where they are protected by the vascular periosteum on the outer side, and fed by the osteoblastic tissue beneath. Here it is that active cellular changes take place which lead to the circumferential growth of the bone and thickening in response to injury or infection.

While the life and growth of a bone is entirely dependent on its vascular supply, these vessels which circulate in the interior of the bone (the nutrient, the epiphyseal, and the articular) are readily liable to thrombosis in the presence of infection. The rigid walls of the Haversian canals allow the channels to be blocked by inflammatory exudate, and a large part of the vascular supply may be cut off. The periosteal vessels are much less liable to such a complication, and for this reason, as will be alluded to later, it is most important to preserve periosteum intact as much as possible.

Etiological Considerations.—In the great majority of cases the injuries are open (compound) fractures associated with a wound of the soft parts; and any of the missiles of war may be the responsible factors.

In exceptional cases the fracture may be closed (simple), as when the limb is struck by a large fragment of low velocity.

In practically every instance the fracture is due to direct injury applied to the bone—rifle bullet, shell fragment, etc.

Pathology.—The degrees of injury to the bone vary within wide limits, and there are three factors upon one or upon all of which the varieties may depend—the shape and type of the missile, the distance from which the projectile was fired, and the portion of the bone which has been injured. The application of this last may seem rather difficult, but an injury to the expanded cancellous ends of the bones is more likely to be accompanied by perforation or slight comminution than one affecting the denser and more compact bone of the shaft.

A working classification of the varieties of possible injury may be arranged as follows:

1. Fissured fractures.
2. Contact fractures.
3. Groove or Gutter fractures.
4. Comminuted fractures.
5. Fractures with loss of substance.
6. Fractures by indirect violence.

Fissured Fractures.—Fissures or cracks in the shaft of the bone are generally in association with other varieties of fracture, but sometimes one finds independent and isolated types of this injury. They are the result of impact by a projectile of low velocity; they may take the form of a single long spiral fracture, or there may be several long cracks and fissures running upwards and downwards in the shaft of the bone. The injury is apt to be overlooked as it may not give rise to any disability or abnormal mobility or deformity.

Contact Fractures.—These are caused by projectiles hitting the shaft tangentially and being arrested by the shaft. Such fractures may be transverse or oblique, and around the actual fracture there is invariably fissuring and occasionally actual comminution.

Groove or Gutter Fractures.—Such injuries as these are caused by rifle or machine gun bullets which strike the diaphysis tangentially and which cause a groove or gutter in the shaft of the bone. From this groove there may be radiating cracks and fissures.

Comminuted Fractures. — Most frequently the bone is shattered into many fragments, and this comminuted type of fracture is the most typical and serious type of bone injury. At the point of impact the bone is shattered into a number of fragments of varying size. Many of the fragments are detached from the periosteum, and by the momentum which has been imparted to them, they are driven widely and deeply into the surrounding soft tissues. Other fragments remain attached to the periosteum. There is always considerable haemorrhage from the damaged bone.

Delorme[1] states that "when the velocity (of the missile) is excessive free splinters are no longer carried along but are violently thrown out in the form of a sheath. They no longer have any exact situation. They bury themselves in the soft parts at a more or less long distance from the track, and some of them break out of the limbs through numerous separate orifices." He further states that "the dimensions of the splinters like their number are inversely in proportion to the velocity of the projectile—the less the velocity, the larger the adherent splinters and the less their number, and inversely."

Fractures with Loss of Substance.—This condition is described separately, as cases are frequently seen in which there is a complete loss of the bony substance with destruction of the periosteal covering. Such conditions are generally caused by large fragments of shell or bomb, or by rifle bullets which have become deflected. Not only is the continuity of the bone destroyed, but there is destruction of a large amount of the soft tissues.

[1] Delorme, *War Surgery.*

Fractures by indirect Violence.—These fractures are associated with a lesion elsewhere in the same bone. It sometimes happens that the shaft of the bone is injured by the missile, and at a distance from the direct wound there is a single oblique fracture caused by indirect violence to the shaft.

The uncomplicated Process of Repair of Fractures.—This may be summarised as occurring in distinct stages.

1. *Blood Clot.*—When a fracture occurs in the continuity of a bone, the interval between the broken ends becomes occupied and infiltrated with blood clot.

At first it is a simple red clot of coagulated blood, but in the course of forty-eight hours it becomes infiltrated by leucocytes, connective-tissue cells, and osteoblasts. From the adjacent marrow and periosteum capillary loops grow into the altered clot, and the original blood clot soon becomes metamorphosed into an area of granulation tissue or procallus.

2. *Granulation Tissue or Procallus.*—This in appearance and histologically is indistinguishable from granulation tissue elsewhere. The majority of cells in it are osteoblastic, and by their agency calcium salts are deposited in the intercellular tissue. The generalised deposit of the calcium salts converts the granulation tissue into calcified granulation tissue or callus.

3. *Callus.*—At first the callus is soft and, as a homogeneity between it and the hard bone develops, the callus becomes firmer and harder. It is laid down in the area occupied by the original blood clot, but only at such distances from the broken bone surfaces as can be traversed by the osteoblasts.

An ossification of the callus into hard bone completes the process of repair. In many cases the transformation of callus into bone is preceded by a stage of cartilage. This is a conspicuous feature of fracture repair in animals—it is of no practical importance.

4. *Ossification of Callus.*—To begin with there is a mere

scattering of earthy salts throughout the granulation tissue, but soon the deposit of calcium becomes denser and there is a formation of calcium round all the blood-vessels and in the cellular tracts.

The dense bone near the broken ends becomes eaten into by cellular activity, and this is evidenced to the naked eye by little points filled with granulation tissue. This osteoporosis proceeds rapidly in young bones and in bones which are injured near the vascular articular ends; the process is slower in the bones of adults and in parts near the centre of the shaft.

Thus there are two processes proceeding simultaneously—a process of rarefaction in the adjacent hard bone, and a process of condensation and ossification in the new-formed callus. The process of rarefaction ceases and the whole mass becomes solid by a deposit of bone lamellae in all the open spaces, until no channels are left except the Haversian canals.

Projecting portions of callus and spicules of the original bone are gradually absorbed through the medium of connective-tissue cells and osteoclasts. This is more noticeable on the convex side of a fracture; on the concave side of a fracture, and in positions generally which are subject to stress and strain, the bone becomes buttressed and the bone scar is thicker and harder than normal bone.

The quantity of callus which is formed depends upon the vascularity of the injured bone, the area of the wounded surface of the bone, the presence of a slight degree of mobility between the broken ends, the presence of a well-resisted mild infection, and on the absence of a destructive infection.

In conducting the treatment of a healing fracture there are certain principles therefore which must be borne in mind.

Ideal healing is only possible when from the outset the broken bone surfaces are held in such close apposition that the gap between the broken ends is only a linear one.

When the broken surfaces are not in apposition healing is

by granulation or callus excess, and all the bone fragments are welded into a mass of new tissue which fills up the interstices and which has subsequently to be largely reconstructed so as to meet the strain and stress which the injured part may be called upon to bear.

In the presence of a marked displacement, if the broken surfaces are brought together while the ends are covered with granulation tissue, the opposing surfaces will unite and the bone continuity will be restored. The period during which the ends may be brought together lasts for several weeks, but if cicatrisation of the granulation tissue has advanced before apposition is secured, healing will not occur as the scar tissue is avascular and comparatively acellular. The bone cells and the vessels are locked up in the dense avascular bone tissue.

The Relation of Sepsis to Bone Repair and to Necrosis.—Practically all compound fractures as they occur in war are infected, and the presence of infection may modify very considerably the process of bone repair.

The reaction of a broken bone to sepsis varies very greatly. When the infection is trivial and when the wound is efficiently treated the bone injury may heal rapidly and well.

When the infection is severe a total necrosis may occur, or there may be a partial necrosis, with considerable loss of substance of the bone tissues. Total necrosis occurs much more rarely than one would imagine. Partial necrosis is accompanied by an indefinite delay in healing, and when healing does occur it is generally accompanied by an excess of callus formation.

The nature of the tissue reaction to infection is governed by three features—by the nature and the severity of the infection, by the vascular supply of the injured bone, and by the time at which treatment is begun and the efficiency of such treatment.

The Displacements of the Broken Bone.—The actual force

of the missile may produce a displacement. The injury causes a primary muscle spasm which possibly leads to a displacement; but directly after the wound, and probably in proportion to its severity, the muscles are almost paralysed by the force of the blow. This condition lasts from one to two days, and during the period any displacement which has occurred may be restored with a minimum of extension force.

This interval of paralysis is followed by one of muscular irritability, especially marked if the limb has not been properly immobilised, and the intensive muscular spasm during this period may lead to considerable shortening and bone deformity.

Symptoms and Physical Signs.—If you ask a wounded man suffering from a compound fracture of a long bone to recount to you his sensations, he will generally tell you that his first experience was a sudden numbing yet painful sensation in the limb. Immediately all power in the limb was lost, and if the lower limb was affected he fell to the ground.

After an interval, which varies widely from half an hour to several hours, the numbing sensation passes away, and if efficient splinting is not applied it is replaced by the most intense and agonising pain at the site of injury.

The physical signs are generally sufficiently obvious. The position of the soft tissue wound is suggestive of whether or not the bone is damaged. The limb below the site of injury, if unsupported, generally takes up an abnormal position, the exact relation of which is generally governed by the laws of gravity and by the original displacement of the broken bone.

When the fracture is of the comminuted type, spicules of bone may be seen in the exit wound of the soft tissues. Persistent venous oozing from a limb wound is extremely suggestive of a bone injury, and drops of fat are generally recognisable in the haemorrhage.

Diagnosis.—The diagnosis is generally quite obvious. It

is made by the appearance and displacement of the limb; by direct inspection of the bone injury when the wound in the soft tissues is being cleaned up; and by the X-ray. The size of the wounds of entrance and exit, together with the direction of the track, gives important information. We have already drawn attention to the presence of bone spicules and fat globules in the aperture of exit.

In those cases where there is a considerable degree of comminution, palpation of the injured part reveals a diffuse crepitation, but it is important that no undue manipulation of the injured part should be made, as unnecessary damage and further tearing of fragments may in this way be induced.

The diagnosis of the type of fracture and the presence or absence of foreign bodies is made by radiographic examination.

X-ray Examination.—The necessity for X-ray examination in gunshot wounds of the bones is even greater than in simple fractures. The examination is essential in order to ascertain the position and the relations of the fracture, and to detect the presence of foreign bodies.

For example, it is only by the aid of an efficient radiogram that one can assure oneself of the direction and extent of a fissured fracture.

It is important that several views of the limb should be taken—at least two views in planes at right angles to each other. If the views are taken in antero-posterior and side-to-side directions, it has been objected that considerable disturbance is imposed on the patient. In a bad case it is probably better to take the views obliquely at right angles to each other, but if the limb is efficiently splinted and slung off the bed, any number of X-ray pictures may be taken with very little disturbance to the patient.

It has been urged that the X-ray should be taken when the limb is properly supported and orientated in the apparatus by which the fracture is eventually to be treated. This prin-

ciple has the advantage that subsequent examinations are made in corresponding positions, and accurate information is obtained as to progress.

Prognosis.—The prognosis must be considered from the points of view of the life of the patient, of amputation, and of the future usefulness of the limb.

Prognosis regarding Life.—Compound fractures of the larger bones, and especially of the femur, are accompanied by a great degree of shock; and a certain proportion of these cases die before adequate treatment can be begun. Apart from this, the risk to life in the later history of the case depends upon the development of complications, and there are two which are especially dangerous.

The first of these is gas gangrene infection of the wound. If it develops, it appears early, and it is accompanied by a large mortality. The second risk is that of progressive local sepsis with septicaemia. Improved methods of treatment have lessened the risk of this complication.

Prognosis regarding Amputation.—Immediate amputation may be necessary when the fracture is associated with very extensive injury to the soft parts, or with damage to the important vessels and nerves of the limb.

Later amputation may be called for as a life-saving measure when a local sepsis has developed which refuses to yield to treatment, and which by its persistence and absorptive effect is beginning to endanger the life of the patient.

Prognosis regarding the Usefulness of the Limb.—At one time it was thought that muscular adhesions would have proved one of the most troublesome complications in retarding the future usefulness of the limb. The later history of these cases shows that this is not a troublesome feature, and when it occurs it is overcome by movement and massage. Adhesions in the adjacent joints may produce considerable disability. It is chiefly in the bone itself that the complications appear which

endanger the future usefulness of the limb, and a prognosis is incomplete which does not take their possible development into account. The complications are those of deformity from overlapping; deformity from angulation; fibrous union with a flail limb; non-union; adhesions or actual ankylosis in the neighbouring joints; and paralysis from secondary nerve involvement.

General Principles of Treatment.—The treatment of gunshot fractures at the beginning of the present war was unsatisfactory—this was because one dealt with a new problem by old methods.

In previous wars the dangers accompanying these wounds were fully recognised, and little or no attempt at conservative treatment was made—an open comminuted fracture was treated by amputation.

When these cases came to be dealt with in 1914, and the early months of 1915, it was felt that every reliance might be placed on the natural resistance of the human body, and on the germicidal action of powerful antiseptics. Experience soon showed that these factors were insufficient, and new principles of treatment were adopted which have effected a great improvement in the results of these cases.

The underlying features of a successful treatment are: (1) To keep the main portions of the injured bone in correct position; (2) to remove all infected foreign bodies, and, as far as possible, all grossly infected tissues; (3) to counteract any infection which has already occurred, and to prevent fresh infection.

If these principles are adhered to, it may be expected that union of the bone and healing of the soft parts will follow.

Fractures in which there is no wound and fractures in which no infection has occurred are treated upon the ordinary lines of a simple fracture, but these two groups form a very small proportion of the whole.

Hey Groves has enumerated certain essentials of successful treatment, and we cannot do better than quote his remarks verbatim.

"1. The limb must so be placed that the wound can be frequently dressed.

"2. Immobilisation must be effected in such a way that pain is reduced to a minimum, and healing allowed to proceed without interfering with wound treatment.

"3. The infected wound must be treated thoroughly by the removal of foreign bodies and the provision of free and adequate drainage at the earliest possible moment. The wound must further be treated by frequently repeated or continuous methods which remove septic discharges and restore it to a healthy character.

"4. The main fragments of the bone must be placed in correct position as regards alignment, rotation, and length, until union has taken place.

"5. Small fragments of bone must be left in their place when dealing with broken shafts. If the main fragments are properly placed and held, the small bits will usually come into sufficiently good line for practical purposes.

"6. The correct placing of the limb and its fixation must be carried out directly after the first wound toilet, so that proper bone union may be going on at the same time that the wound is being brought into a healthy condition and healing of the soft parts is taking place.

"It is folly to first produce malunion, and then have to correct it.

"7. The uninjured parts of the limb must be maintained in health and functional usefulness as far as this can be done without interfering with the union of the bone and the soft parts."

The Treatment of the Soft Tissue Wound.—In the chapter on general wound treatment we have dealt in considerable

detail with this problem, and the remarks which we then made apply equally well in this relation. Unless the wound is small and uninfected, it should be treated by excision and the thorough removal of all obviously infected tissues. A careful search is made for foreign bodies and these are removed. Both entrance and exit wounds are similarly treated.

The wound surfaces are then retracted to such an extent as to secure complete exposure of the injured bone.

The Treatment of the Injured Bone.—When efficient retraction has exposed the injured area the damaged bone is carefully inspected. With all gentleness, yet with efficiency, a careful toilet of the broken bone is carried out. There is the scrupulous search for foreign matter of any description—small fragments which have become completely detached are removed as their viability has been destroyed. If these are left in the wound they become necrotic, and they remain as foreign bodies keeping up a persistent irritation. Every effort must be made to conserve fragments which retain any periosteal attachments, and in the case of large detached fragments it is better to leave them *in situ*. Bleeding is arrested as much as possible. The exposed surfaces of the injured bone may often be carefully curetted—the open medullary canal may be similarly treated.

When there are fissures and cracks running to a distance from the main fracture, they should not be opened up or disturbed, as doing so will only tend to extend infection. By the careful replacement of fragments, the contour of the broken bone should be restored as completely as possible.

Subsequent Treatment of the Wounds.—When the toilet of the soft tissue wound and of the bone wound has been completed, one has to decide whether the future treatment is to consist of primary closure of the wound or of temporary retention of an open wound. This decision will be governed by the amount of infection which was originally present in

the wound, and by the degree of thoroughness with which it has been possible to excise and cleanse the wound.

If the original infection has been slight, if efficient treatment has been carried out at an early stage after the infliction of the injury, and if a satisfactory wound toilet has been possible, it is generally advisable to close the wound primarily. The majority of surgeons apply some form of antiseptic to the interior of the wound before closure, and excellent results have been recorded from B.I.P.P., flavine, and eusol. The application of soap solution has also given very good results.

In circumstances which are adverse to a primary closure, the wound is left open and treated by the technique of Carrel or of Wright.

Immobilisation of the Fracture.—Immobilisation is one of the necessities for successful union of the broken bone, and it is secured by means of splints.

Many Continental surgeons advocate the use of plaster of Paris as an efficient immobilising agent, and it certainly fulfils the purpose of fixation of the broken bone.

Its use has great disadvantages. Efficient extension becomes impossible. In the early stages of wound treatment it is inapplicable unless applied in some removable way (Croft's splint), for during this period infection may necessitate further incision of the tissues.

When the wound discharges are at all profuse it is impossible to prevent the case from becoming fouled. Its efficient application is extremely difficult, and can only be carried out after prolonged practice.

Surgeons employed the plaster method because they were dissatisfied with the immobilising splints which then existed; but a great deal of ingenuity has lately been expended, and now efficient splints have been evolved for dealing with fractures in any situation. The individual splints are considered from the local standpoint.

A satisfactory splint is one which ensures the following points: (1) An accurate adjustment of the broken fragments; (2) immobilisation of the fragments; (3) it permits the adjustment of efficient extension; (4) it permits easy access to the wound for purposes of dressing; (5) it is comfortable to wear.

The Extension of the Fracture.—It may be said that a displaced fracture can only be restored to a correct position by extension. It is the cardinal act of fracture treatment, for by it the displaced fragments are brought into position and afterwards maintained in the proper position.

Methods of Extension.—The extension force may be applied to the surface of the limb, or it may take its fixation from the bone itself. Surface extension is commonly applied in one of two different ways. Adhesive plaster may be used. Broad strips of zinc oxide plaster (2½ inches wide) on stout canvas are applied as high up as the wound in the injured part of the limb permits. These are affixed by circular turns of similar strapping of a narrower (1 inch) and thinner kind; the whole limb being covered in except the points over which the circular turns are omitted. Bony prominences are protected by pads of lint or gauze, and the whole is covered with a firm roller bandage. The object is to distribute the pull as widely as possible over a large surface of the limb and yet to avoid constricting bands, to prevent oedema, and to leave the joints free for early movement.

In the second method of superficial extension, the material is fastened to the surface of the limb by means of some kind of glue. There are several varieties of glue in use, and we give the details of three different varieties. A and B are associated with the name of Major Sinclair, R.A.M.C., and heat is required in their preparation and application. The third is called Heusner's glue, and it has the advantage that no heat is required in its use.

A. ℞

Ordinary glue	50 parts.
Water	50 „
Glycerine	2 „
Calcium chloride	2 „
Thymol	1 part

The glue is dissolved in the water with the aid of heat and the other constituents are afterwards added.

B. ℞

Isinglass	50 parts.
Glue	50 „
Water	50 „
Calcium chloride	2 „
Tannic acid	12 „
Thymol	1 „
Glycerine	2 „

The isinglass and the glue are dissolved in the water, and the other constituents are afterwards added. The calcium chloride absorbs moisture from the skin, and the thymol prevents decomposition occurring.

Heusner's glue is made as follows:

C. ℞

Resin	50 grammes.
Alcohol	50 „
Benzine (pure)	25 „
Venice turpentine	5 „

The resin is dissolved in the alcohol, and the benzine and the Venice turpentine are then added. Methylated spirits may be substituted for the alcohol, and petrol may be used instead of benzine.

Long strips of gauze or of Canton flannel are laid upon each side of the limb, extending upwards as close to the fracture as possible. The strips are spread out to cover as much of

the limb surface as possible, and towards the extremity of the limb the strips are gathered together in a plaited fashion. Bony prominences are protected by small lint pads.

The glue is applied evenly by means of a strong paint-brush or shaving-brush. If one layer of the extension material is insufficient, a second layer may be applied. Over all a roller bandage is firmly and evenly applied.

The ends of the extension material are then secured to whatever means are used for producing the extension—generally a weight passing over a pulley, or some form of spring.

In glue extension it is important that the gauze be allowed

FIG. 13.—The method of applying glued gauze extension to the limb.

to dry on the limb in the position in which it will exert traction, otherwise the skin is pulled on and blisters occur.

Deep or transfixion extension is called for in two types of cases: (1) Those in which extensive injury to the soft parts prevents the application of a surface extension; (2) cases in which surface extension has failed to overcome overlapping and deformity.

Fractures of the femur, tibia and fibula, and humerus may be treated by it; the indications are most common in the first mentioned, and least common in the last named. Indications in the tibia and fibula are intermediate in frequency.

Five different methods of transfixion extension may be mentioned: (1) The transfixion pins of Codavilla and Steinmann; (2) Hey Groves' horse-shoe screw clamps; (3) double

transfixion apparatus (Hey Groves and Lambret); (4) Finochietto's stirrup extension for transfixion through the soft parts; (5) the ice-tongs method.

(1) *Codavilla's and Steinmann's Pins.*—These are highly tempered steel rods of a thickness of $\frac{5}{32}$ inch, $\frac{3}{16}$ inch, and $\frac{1}{4}$ inch, and of a length of 4 to 6 inches.

The best sites for transfixion are as follows: For the humerus, 1 inch above the epicondyles, rather in front of the supracondylar ridge on the inner side and immediately behind the external ridge, so avoiding both ulnar and musculospiral nerves.

For the femur, from the most prominent point of one condyle to that of the other.

For the leg bones, from a point on the internal malleolus two fingers above the tip backwards and outwards parallel to the plane of the sole. For the os calcis, a point 1 inch below the tip of the external malleolus.

The pin may be hammered through the bone, or inserted by a small T-shaped handle.

To insert the pin, the skin, having been prepared with iodine, is drawn up towards the body and nicked with a knife at the point of entry. The pin is drilled through the bone, and its point cut down upon where it emerges against the skin. In this way no open wound is left, as the elastic skin fits tightly around the pin and all tension is avoided. A tiny adhesive dressing may be applied, or the wound may be kept covered with an antiseptic paste.

The sharp ends of the pin are protected with screw caps or corks, and weight is attached by a Y-shaped cord to its projecting ends.

The pin may be left in place from two to four weeks; too long traction causes absorption of the surrounding bone, with resulting sinus formation and possible deep sepsis.

(2) *Horse-shoe Screw Clamps.*—When there is a large

infected wound of the limb there may be some hesitation in driving a steel pin through a large bone on account of the risk of sepsis.

Another contra-indication exists in cases in which the fracture is situated in close proximity to a joint, and in which

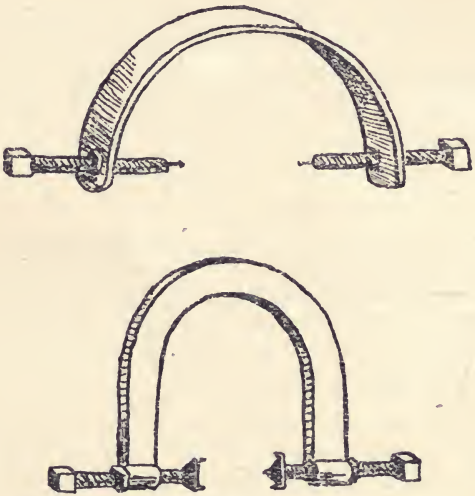


FIG. 14.—Hey Groves' horse-shoe screw clamps.

transfixion might easily lead to further comminution, with possible extension into the joint.

For such cases Groves designed and uses certain fixation apparatus which he describes as "horse-shoe clamps." This is a horse-shoe-shaped piece of steel into the ends of which stout screws are fitted. In one pattern the screws terminate in a point $\frac{1}{8}$ inch thick and $\frac{1}{8}$ inch long, with a drill end. In the other pattern the screws terminate in a little three-pronged plate which loosely swivels on the end, so that the opposing plates can adapt themselves to the sloping sides of the bone,

and get a powerful hold without penetrating any distance into its substance.

Under local anaesthesia small incisions are made over the chosen points and the clamps applied.

In the case of the humerus the points take hold of the most prominent parts of the epicondyles; in the femur they are applied to the condyles; and above the ankle they grasp the malleoli at the level of the joint.

The screws are fastened tightly in place, and secured in position by a locking-nut.

(3) *Double Transfixion Apparatus.*—The principle of this apparatus depends upon transfixing both fragments of a broken bone and making direct extension of one transfixion bar away from the other.

In this way complete command is obtained over both ends of the bone independently of any splint or weight. It is unlikely that the method will have application in Casualty Clearing Station work, but it is well to draw attention to it.

The method may conceivably be applied to any of the long bones, but it is mainly adapted to use in the femur and leg bones.

The apparatus consists of two transfixion pins $\frac{3}{16}$ inch thick and two horizontal extension bars made of a tube into which screw rods $\frac{1}{4}$ inch thick threaded with reverse screws.

The tube is perforated at its centre by holes for a lever, and when it is turned in one direction both the projecting bars are forced apart, while the reverse movement draws them together.

One of the transfixion pins passes through two holes in a circular hoop of steel 6 inches in diameter, $\frac{1}{8}$ inch thick, and 1 inch wide. There are twelve holes in the hoop arranged as six opposite pairs, so that the pin can lie in any one of six different diameters of the hoop. The extension bars fit by an eyelet-hole over the ends of one pin, and by the other they

take a bearing on the steel hoop by a joint which allows of a lateral movement through 30 degrees. This joint can be locked. When the apparatus is in position it permits of movement as direct extension, as tilting of the transfixion pins with consequent correction of angular deformity, and as rotation of one transfixion pin in relation to the other, thus allowing of rotatory displacement being corrected.

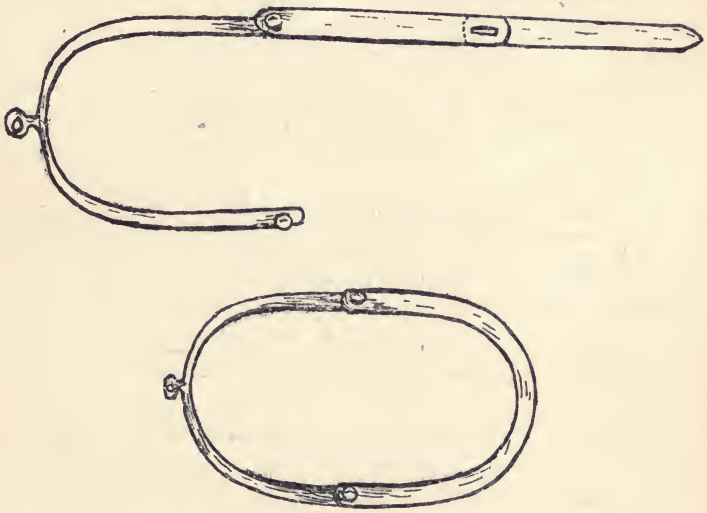


FIG. 15.—Finochietto's stirrup extension apparatus, showing the apparatus provided with attachable introducer, and also as it appears when in position.

The technique of the application of the apparatus is very similar to that described under transfixion.

(4) *Finochietto's Stirrup Extension.*—This consists of a rigid horse-shoe, to which the extension cord is attached, and a flexible metal bar which passes through the soft tissues immediately in front of the tendo Achillis and above the os calcis.

The flexible bar is provided with a removable point to

permit of the insertion. When inserted the free end of the flexible bar is fastened to the end of the rigid horse-shoe.

(5) *The Ice-tongs Method* is now much in use.—The points of the tongs are pushed into the expanded femoral end through small incisions. The knee is bent, and weight extension applied to the handle loops.

Amount of Extension.—The amount of extension force must be sufficient to correct fully both angulation and overlapping of fragments.

The amount varies with the musculature of the limb, and a correct judgment can only be arrived at by repeated X-ray examination in two planes. It is unwise to trust to mechanical measurement as an indication as to whether extension is doing its work or not.

Every effort should be made to secure the best possible apposition before the operative treatment of the wound is concluded, and if the extension is applied before the wound is closed, or the operation otherwise concluded, the best results will be obtained.

As a general working rule, in the early period after injury (*i.e.* during the first week), the following may be taken as average extension forces: for a femur, 20 lbs.; for a tibia and fibula, 12 lbs.; for the arm bones, 8 lbs.; but it must be understood that these figures are only rough guides, and in each case the amount must be determined by the result.

The Direction of the Extending Force.—In certain parts, owing to the greater power of the muscles on one side of the limb than those of the other, there is always a tendency to angulation, and this can be counteracted by suitably adjusting the direction of the extension. In high fractures of the shaft of the femur the lower fragment tends to be adducted, and extension should be in an abducted direction in order to counteract this. Similar contingencies appear in the lower end of the femur, in the lower leg, and in the humerus, and these conditions are discussed under local headings.

The Nature of the Extending Force.—The actual extending force may be obtained by various means—by rubber extension, by weight and pulley, or by a spring. The important feature is to ensure that the extending force is a continuous one.

Operative Treatment of recent Fractures by immediate Fixation of the broken Ends.—In recent fractures there is only one type of this procedure which need be considered: that is, fixation of the broken ends by plates and screws.

To one who has been unaccustomed to deal with war wounds, immediate fixation would appear to offer certain very great advantages. For some time after the fixation is completed there is relief of pain, dressing is facilitated, and transport is simplified. But these advantages are only temporary, and the later disadvantages very much outweigh them. The disadvantages are that the operation necessitates extensive opening up to infection of the soft tissues and the bone marrow; there is a liability to further comminution of the bone; there is a danger that the operation may be followed by extensive necrosis of the bone, and these combined disasters may easily lead to ultimate loss of the limb.

The operation is one which is very rarely permissible in the surgery of a Casualty Clearing Station, but the primary closure of wounds has again brought operative fixation within the bounds of legitimate surgery—anyhow in cases of recalcitrant fractures.

The later Treatment of Compound Fractures.—This includes the very important procedures of massage and movement. Light massage can scarcely be begun too soon; but there are many administrative difficulties which render its use at this early stage impossible.

Movement should be begun on the third to the sixth day according to the nature of the case. All the neighbouring joints are exercised by slow, small, and painless movements—

joints distant from the fracture may be moved some days before those adjacent to it.

In the Casualty Clearing Station there are conditions which render difficult this most important branch of the after-treatment.

Compound Fracture of the Femur.

Compound fracture of the femur by gunshot wound has always been recognised as an injury which is most dangerous to life, and the experiences of the present war entirely confirm the opinion formed in the past.

There are several reasons which account for the gravity of the injury. Shock is generally of the most severe type. In the majority of cases there is the immediate complication of haemorrhage, such large arterial vessels as the femoral and the popliteal may be damaged, either by the missile or by fragments of bone: even in the absence of injury to the large vessels the haemorrhage is considerable. Infection is a common sequel, and the deep position of the bone, covered as it is by large muscles and various fascial planes, may render the infection specially severe and remarkably difficult to eradicate. In the later stages there is the risk of progressive sepsis.

For these major reasons—and there are others secondary and less important—this type of injury will always rank as one of the most serious.

The various considerations which we have discussed under the general heading naturally apply to the local conditions, but there are items which require more detailed investigation; these are the questions of mortality, prognosis, and treatment.

Mortality and Prognosis.—In 1916 Bowlby published the actual mortality of 1000 unselected cases in various Casualty Clearing Stations; he found that the actual mortality was 160, or 16 per cent. But as at least a quarter of these had multiple injuries, he estimated that the mortality of the fractured femurs alone may be taken to be about 12 per cent.

In our own experience this latter figure is approximately correct; from the records of some 130 cases admitted to a Casualty Clearing Station the percentage mortality averaged 11·7 per cent. (June 1916 to September 1917.)

It must be remembered that this figure only applies to those cases which are admitted to the Clearing Station. A considerable number die on the field or in the Field Ambulances, and what exactly this proportion may be, we cannot at present say. Further, a certain proportion of the cases which are evacuated from the Clearing Stations die in Base Hospitals, but with this group we are not concerned.

Apart from the development of possible complications, fractures in the upper half of the femur are more serious than fractures in the lower half.

Treatment.—In the general section we have dealt with the treatment of the soft tissue wound, and the same principles apply.

It is wise to gain admission to the injured bone through the wounds of entrance or exit, possibly through both. These wounds are thoroughly excised and cleaned, and free exposure of the damaged bone must be obtained.

Occasionally it may be permissible to expose the damaged femur through a separate incision made in healthy tissue. The situation of the incision is chosen in a suitable anatomical position, and, if required, it is generally made on the anterior aspect of the limb. This procedure should not be adopted unless for special reasons, as it necessitates the opening up of fresh tissues, and a spread of infection is liable to follow. We have occasionally employed this method in dealing with high fracture of the femur when the entrance and exit wounds were in situations specially difficult of access.

When the injured bone is exposed it is treated on the principles which we have already laid down.

The Application of the Splint.—The question is constantly being asked, What is the best type of splint to apply in

compound fracture of the femur? Much has been written on the subject and a number of different splints have been evolved. We propose to divide the different types of splints into three groups—and it must be remembered that we are dealing only with those splints which are of use in Casualty Clearing work. Now in this work there are certain points to be kept in view, and the choice of splint will, of necessity, be modified by such. The points to be kept in mind are: (1) In all probability limitation of time and of personnel make it impossible for each case to receive the individual post-operative attention which it will receive in a base or home hospital; (2) the splint must be such that it is adaptable for early transport. Remembering these two qualifications the three groups of splints which we propose to discuss are (*A*) straight splints, (*B*) angled splints providing flexion of the neighbouring joints, (*C*) special splints for use in fracture of the upper end of the femur.

(*A*) **Straight Splints.** — Of the straight splints the best-known are — the Thomas knee splint, the Wallace-Maybury splint, and the Page splint.

Advantages.—Taken as a group representative of the straight splints, these appliances have certain great advantages. They are not cumbersome. They are standardisable, and the standard patterns are adaptable to the great majority of individual cases. The application of the splints is simple and is effected with the least possible disturbance of the patient. They secure adequate fixation of the limb with steady extension in the long axis of the limb.

When the splints are in position, access to any part of the limb for purposes of dressing is possible, and nursing duties are rendered simple.

Disadvantages.—Certain disadvantages of the method have been urged. An objection usually quoted is that these splints hold the main joints in a position of full extension, which by

reason of the powerful flexor muscles, means one of maximum tension, and the rigid knee which cannot be bent without undoing the extension becomes fixed and painful. Probably with much less ground other objections have been raised —that the ring or half ring at the top of the splint is uncomfortable for the patient, and that it is difficult to maintain effectual extension without inducing painful counter-pressure on the perineum.

Thomas Knee Splint.—That this splint has given satisfaction may be judged from the fact that it is now in general use as the first-aid appliance for compound fracture of the femur. It has been adopted on account of the ease with which it can be applied, the excellent fixation which it affords, its suitability for transport, and the adaptability which it shows for extension purposes.

FIG. 16.—Thomas knee splint—bed pattern.

First-Aid Application of Thomas Knee Splint.—The method of application in first-aid and field ambulance work differs in several respects from the technique which is adopted in the Casualty Clearing Station. We shall briefly describe the method as it will be constantly met with.

When first seen the man's trousers are slit open to expose the wound, and a suitable first-aid dressing is applied. A Thomas knee splint is chosen of a suitable length and size of ring—it is important that the ring be an easily fitting one with plenty of space in front between ring and front of thigh. The splint is prepared by slinging across from bar to bar a series of bandages so arranged that they will support the posterior surface of the thigh and calf when the splint is in position.

The ends of the bandages are looped round the lateral

bars and fastened in place by safety-pins. In this way any necessary readjustment is easily carried out. Three-inch flannel bandages are the most suitable for the purpose.

Several small pieces of Gooch splinting are placed around the broken thigh—four are generally sufficient, and these are fastened in place by a couple of triangular handkerchiefs. The splint is now placed in position, the man's boot being kept on, and there being no disturbance of his garments except the slitting up of the trousers which is necessary for exposure of the wound.

A couple of clove-hitches are placed around the ankle over the boot, one on the inner and one on the outer side, so that the pull on the leg is taken from the prominence of the heel and the top of the instep. Extension is obtained by tying the ends of the clove-hitches to the transverse bar at the bottom of the splint. Before tying them to the foot of the bar a special hitch may be taken around the lower part of each lateral bar.

The centre of a triangular bandage, folded to a quarter fold, is laid over the front of the knee, and the ends being carried underneath the lateral bars, they are tied together in front of the knee. In this way the limb is secured to the splint and flexion of the knee is prevented.

Over all a roller bandage is placed fastening the limb to the splint. The stretcher on which the man is placed is fitted with a stretcher suspension bar, and to this the splint is slung by pieces of bandage.

When treated in this way compound fractures of the femur arrive at the Casualty Clearing Station in an exceedingly good condition, and the splint should not be removed until the patient is on the operating table and under the influence of the anaesthetic.

The following detail of the front line application of the Thomas knee splint is here reproduced by permission.

The Thomas Outfit consists of—

Stretcher on trestles.
Blankets, 3. Primus stove.
Thomas's splint (largest size).
Reversible stirrup (Sinclair's).
Suspension bar.
Flannel bandages (6 yards), 3.
Triangular bandages, 4.
Dressings.
Safety-pins.
Gooch splinting (10″ × 6″, 8″ × 6″).

Personnel required:—Operator 1. No. 1 Assistant. No. 2 Assistant (if available).

When not in use the splint is kept hung up. The five slings of flannel bandage are rolled round the inner bar of the splint, the leather is kept soft by saddle soap, and the iron bars are smeared with vaseline.

Indications of Front Line Application.—1. For all fractures of the thigh bone, except where there is an extensive wound in the upper part of thigh or buttock, which would interfere with the fitting of the ring.

2. In severe fractures about the knee-joint or upper part of the tibia.

3. In certain cases of extensive wounds of fleshy part of thigh.

Detail of Thomas's Splint Drill.

On the word "One."—The stretcher, placed on trestles with a Primus stove beneath, is prepared as follows: The first blanket is folded lengthwise into three, two folds lie on the stretcher, one hangs over the side. The second blanket is arranged in the same way, one fold hanging over the other side of the stretcher.

The patient is now placed on the prepared stretcher and lies on four folds of blanket; the two folds hanging down form a hot-air chamber. The third blanket is placed across the patient's chest, while the splint is being applied.

On the word "Two."—The No. 1 assistant stands at the foot of the stretcher facing the patient and opposite the injured limb. Grasping the heel of the boot with his right hand and the toe with his left, keeping the arms straight, he exerts a steady pull,

thereby producing the necessary extension. The No. 2 assistant supports the injured part above and below the fracture.

On the word "Three."—To form the modified clove-hitch, the operator takes a length of 9 feet of flannel bandage. Holding it in the left hand by its mid-point, he grasps the centre of the left half with his right hand, palm to the right, and makes a loop which is carried up and passed behind the left hand, thus forming a clove-hitch with a diameter of 10 inches.

This is applied over the boot, with the short end on the outer side; the long end is carried under the instep, up and through the loop round the ankle. The two extension bands thus produced are ready to be attached to the splint later on. Care must be taken not to constrict the ankle.

On the word "Four."—The operator threads on the splint; No. 1 assistant removing and re-applying upper and lower hands alternately to allow the ring to be passed over the foot. The splint should be pushed up under the buttock as far as possible, care being taken to keep the notched transverse bar horizontal. No. 2 assistant, as before, steadies the thigh.

On the word "Five."—1. The extension bands of the clove-hitch are tied round the notched bar at the end of the splint as follows:—The outer band is passed over and under the bar, round the notch, drawn taut, and held over to the opposite side. The inner band is passed under and over the bar, then also round the notch where it crosses the first band and prevents its slipping. The two are finally tied off by a half bow.

2. The middle sling is tied off over the outer bar, No. 2 assistant keeping the knee partly bent.

3 and 4. The slings behind ankle and calf are tied, so that the leg rests in a shallow trough, half in and half out.

5. To prevent the leg rising off the splint a narrow fold bandage is placed across the leg, just below the knee; the ends are carried down between the leg and splint, brought up outside the bars, and tied off. The lower limb is now firmly fixed in a

position of extension, and it may be moved without causing pain to the patient or damage to the injured part.

On the word "Six."—The wound is exposed by cutting away the overlying portion of trousers on the wounded part of the thigh, and the dressings are applied.

On the word "Seven."—The Gooch splints are now applied. The short piece is placed behind, and secured by tying the remaining two slings. The long piece is placed on the front of the thigh, care being taken to avoid pressure on the knee-cap. The whole is now retained in position by two narrow fold bandages, carried round the thigh outside the bars of the splint.

On the word "Eight."—The stirrup is "sprung" on to the splint above the ankle, its foot towards the stretcher. A bandage is then applied to form an additional sling, which by a figure-of-eight turn prevents lateral movement of the foot.

On the word "Nine."—The extension bands are tightened, and a small piece of wood or a nail is introduced to increase the tension by twisting up as required.

On the word "Ten."—A pad is placed inside the ring on the outer side of the thigh to act as a wedge and prevent undue movement.

On the word "Eleven."—The suspension bar is fitted to the stretcher with the "grip" away from the rackets. The splint is slung up not less than a hand's-breadth from the horizontal part of the suspension bar. To damp down the side movements, lateral tapes are tied to the uprights; they should not be tight. For the journey in the motor ambulance an additional band may be passed from the splint round one handle of the stretcher; this prevents excess of vertical movement.

On the word "Twelve."—Hot bottles are applied. The third blanket is folded into two lengthwise, and laid over the patient. The hanging folds of the first and second blankets are brought up over this so that the patient is evacuated with four folds of blanket on top as well as underneath.

Application of the Thomas Knee Splint after Operation.—In Clearing Station work the Thomas knee splint is in general use. It is efficient, it is easily obtainable, and its application is comparatively simple. It has one disadvantage—it is difficult to provide a continuous and efficient extension; however, there are ways of overcoming this difficulty.

In choosing a suitable splint, attention is paid to the length, to the breadth, and to the size of the ring.

In our experience it is quite exceptional to find the Thomas knee splint[1] with a properly made ring; it ought to be ovoid

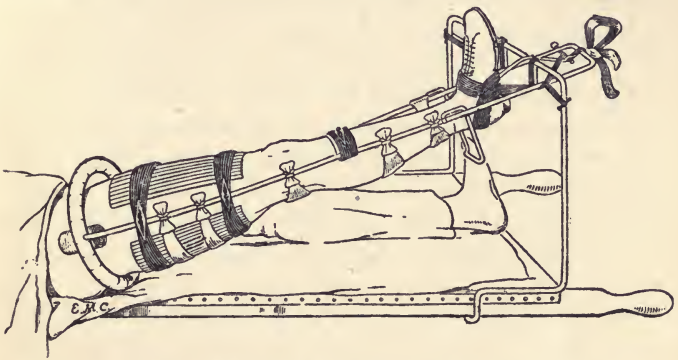


FIG. 17.—Thomas knee splint as applied on the field for compound fracture of the femur. (From official circular.)

in shape, flattened in front, expanded behind, and wider on the inner than on the outer side. The uprights are brazed to it at a lateral and antero-posterior inclination 135 to 145 degrees respectively. There are definite reasons for the irregular shape of the ring and its inclination. It is expanded behind to fit the thickness of the buttock, the antero-posterior inclination allows the ring to rest with comfort beneath the tuberosity of the ischium, the lateral inclination is necessitated by the greater

[1] The Thomas splint has now been standardised by Colonel Sir Robert Jones, R.A.M.C. (T.).

length of the outer bar which rises above the level of the great trochanter. The padding of the ring should be thickest on the posterior and inner surfaces where the greatest weight is borne.

The splint should not be provided with the posterior leather supports, and the lower end should be of the bed-splint variety, not of the ambulatory type.

Method of Adjustment.—When the local operative treatment has been completed the limb is passed through the ring so that the extremity lies between the uprights. The ring is carefully adjusted in position, special care being taken that it fits accurately upon the tuber ischii. The perineum should be carefully cleaned, dried, and dusted with a talc or chalk dusting powder.

Support is provided for the posterior aspect of the thigh and calf; it may be by bandages pinned around the lateral bars of the splint. Strips of rubber bandages or portions of inner rubber tyre answer excellently, and Sinclair has suggested that they may be attached to the splint bars by ordinary metal paper clips; the rubber suspension is yielding and comfortable. We have generally used a rigid support in the shape of pieces of zinc gauze made concave to receive the limb in a comfortable position and fixed in place by being doubled around the splint bars. Two pieces of zinc are required: one supports the thigh, the other supports the leg below the knee. This idea we also owe to Sinclair. Zinc supports have the disadvantage that while they are in position they prevent the taking of an efficient X-ray photograph.

Whatever method of support be used it is a good plan to secure the inner side first, the outer side being secured when the position of the limb has been accurately adjusted.

The first sling to be fastened should be the one under the fracture. This should be tighter than the others. It is important to preserve the natural bow of the femur.

Extension is now applied to the limb by one of the methods

already described. Generally a surface extension is provided by applying strips of gauze upon the sides of the limb, carried upwards to as near the fracture as possible and fastened to the limb either by Sinclair's or Heusner's glue. The malleoli are protected by pads of lint, and a roller bandage is applied over the extension material.

Very rarely conditions may arise which call for a deep or transfixion extension. A low fracture with much displacement of the bone fragments may require extension by means of a Steinmann's pin passed through the femoral condyles. Multiple wounds of the leg and thigh may necessitate a transfixion extension at the ankle by Steinmann's or Finochietto's apparatus.

It is in providing the continuation of the extension that we recognise the disadvantage of the Thomas knee splint. There are several plans which may be adopted. The ends of the extension material may be carried once spirally round the lower end of the splint bars and tied over the end transverse bar: this provides a certain amount of extension, but it is unyielding and it does not accommodate itself to the possible readjustment of the limb.

Rubber tubing may be fastened to the ends of the extension and the tubing is secured to the transverse bar. This may be tightened as required by inserting a piece of wood into the loop of the rubber and tightening it after the manner of a tourniquet. Lastly, it is possible to provide a weight extension —fastening the lower ends of the extension to a stirrup and carrying the weight cord from the stirrup over a pulley.

The foot should be kept at a right angle, and this may be done by a figure-of-eight bandage carried round the splint and round the foot. A sliding foot-piece which fits on to the lateral bars is provided with the splint, and the sole of the foot is supported by a small plate of zinc folded around the foot-piece, by Sinclair's skate, or by a piece of gauze glued to Sinclair's prop.

The foot-piece slides upwards and downwards upon the lateral bars and so adjusts itself to the degree of extension.

When the splint has been adjusted and extension provided, the whole limb and splint should be covered in with a roller bandage. This is not absolutely necessary while the case is under treatment and observation in the Casualty Clearing Station, but it should always be applied before transport.

Such, briefly, is the method of application of the Thomas knee splint, and it gives very general satisfaction.

The splint is suspended from some kind of suspension bar, or suspension is provided by the counterpoise method described by Blake and Sinclair.

The Page Splint.—The original Page splint was made from the malleable metal provided in the Field fracture box. Standard sizes are now issued made from rigid metal. It is a modification of the Thomas knee splint. At the upper end there is a half ring which lies posteriorly and is adjusted to the tuber ischii. Opposite the centre of the calf there is a limb support which keeps the splint elevated from the level by about a foot.

The method of its application is very similar to that which we have described in discussing the Thomas knee splint.

Page describes its application as follows:

"An extension stirrup is fixed to the injured leg, long axis traction is then made on the injured limb and it is steadily raised through about 30 degrees. The splint, with slings in their approximate place, is then laid below the leg, and the crutch of the splint is made to abut against the ischial tuberosity. The limb is then lowered on to the slings. . . . A webbing strap is applied round the bottom notch of the splint and the extension stirrup. The slings are then adjusted so that the limb lies comfortably in about the midplane of the splint. Two webbing straps are carried across the front of the limb, one between the extremities of the crutch, and the other just below the knee. These two straps need only be

tight when the patient is being moved about or rolled on his side for dressing; the extension strap should always be kept taut."

This splint has one outstanding disadvantage—unless extension is accurately and continuously applied, the half ring at the upper end is very apt to be displaced.

The Wallace-Maybury Splint.—This splint was originally described in the *Lancet* of 13th February 1915 (p. 323). It is a modified Thomas splint, extension being secured by means of a powerful screw attached to the foot-piece of the splint.

The following is the authors' account of the application of the splint:

"First of all, two strips of strapping are applied to the outer side of the leg as in the ordinary stirrup extension. The lower end of each piece is then split longitudinally, and the two tails thus formed are brought respectively over the upper and lower surface of the transverse foot bar, and secured in a figure-of-eight manner. The same is then done on the opposite side of the limb. A piece of gamgee tissue is then wrapped around the foot and a figure-of-eight bandage applied to fasten the foot to the foot-piece. Two clove-hitches are then placed over this one on either side, so that the pull on the leg is taken from the prominence of the heel and the top of the instep. The two ends on either side are then fastened to the transverse foot bar. By means of the strapping extension, the bandages, and the clove-hitches, the pull on the limb is evenly distributed. Extension is then produced by turning the traction screw until the splint is steady."

Certain modifications of the splint are in use. The outer limb is sometimes cranked, and this facilitates dressing of wounds on the outer aspect of the thigh. Originally the vertical bars were screwed into the thigh ring—a modification is in use in which the bars fit into sockets in the ring, thus

permitting a certain amount of antero-posterior movement. This detail is said to increase the comfort of the splint.

We have used this splint more generally than any of the others. It is an expensive splint and sometimes difficult to obtain in any number, but we have had the greatest satisfaction from its use. We have applied it in a very similar manner to that which we have described in dealing with the Thomas knee splint. We have fastened the extension ends to the foot-piece or to the sliding transverse bar which carries the screw.

(*B*) **Angled Splints.** — In theory, angled splints which provide flexion of the joints adjacent to the fracture have much to recommend them. They ensure extension, secure flexion of

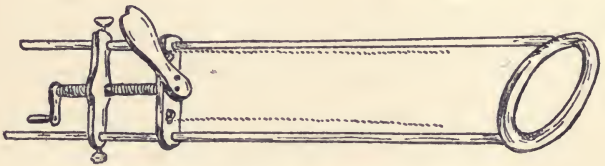


Fig. 18.—The Wallace-Maybury splint.

the joints and free access to the limb without disturbance. But in practice they are found to possess certain positive disadvantages. They require a great deal of patience, experience, and care for their correct adjustment. If infection of the wound develops, it would seem that they encourage an upward burrowing of the infection. For purposes of transport they are unwieldy and unstable.

We propose to draw attention to three splints representative of this group which are, or have been, in common use: (1) The Balkan frame splint, (2) Hodgen's wire cradle splint, (3) the fixed wire cradle splint.

(1) **The Balkan Frame Splint.**—This method was introduced during the course of the last Balkan War, hence its name.

Uprights are fastened to the head and foot of the bed, the

lower upright being at least a foot higher than the upper one. The top of the two uprights are connected by a bar which necessarily slopes downwards towards the head. Two folded sheets are passed around the limb: one round the thigh, and one round the leg below the knee. The ends of the sheets are carried round the horizontal bar and pinned in position. In

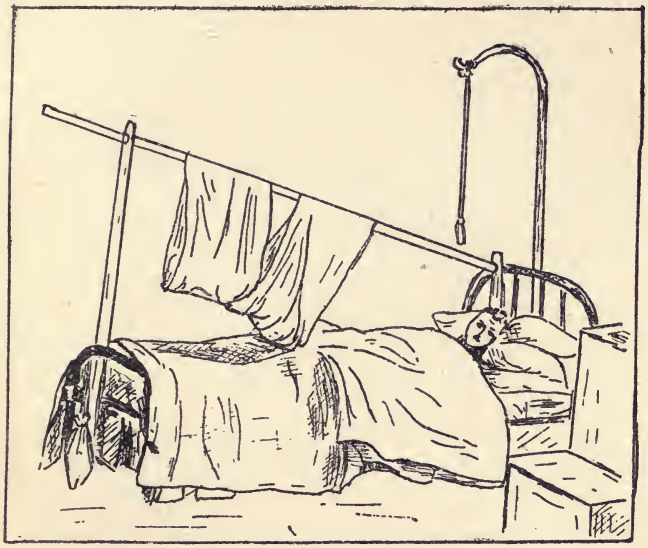


FIG. 19.—The Balkan frame.

this way the thigh is slung by one support, and the leg below the knee by the other.

The thigh is generally flexed to an angle of about 30 degrees, and the knee is slightly bent to a comfortable position. A curved gutter splint made of sheet metal, thick cardboard, or poroplaster, and placed on the thigh sling beneath the fracture, will make the apparatus much more comfortable, and prevent sagging at the site of injury.

This, at the best, is but an improvised splint, and its use is only justified when no more suitable appliance is available. It is of course quite unsuitable for transport, and the extension which it provides is imperfect.

(2) **Hodgen's Wire Cradle Splint.**—This consists of a wire frame, to one side of which a series of strips of flannel about 4 inches wide are attached. The frame, which extends from Poupart's ligament to well beyond the sole, is placed over the front of the limb and the loose ends of the flannel strips brought round behind the limb and fixed to the other side of the frame, convert it into a sling. Extension strapping or extension glued in position is fastened to the sides of the limb, and the ends of the extension are tied to the end of the frame.

The limb is suspended on the splint by means of cords passing obliquely over a pulley attached to an upright at the foot of the bed; the weight of the limb is made to act as the extending force. Thus, the whole limb from the hip downwards is swinging in mid-air, the hip-joint is flexed to an angle of about 30 degrees, and there is a moderate amount of flexion permitted at the knee-joint.

Patients will tell you that when the limb is at rest the splint is an exceedingly comfortable one, but the least manipulation imparts a swinging motion to the limb, and this at once produces pain.

Again the mechanical extension is by no means perfect. Suspension and extension are both brought about through the pull of an oblique cord, and any alteration in suspension causes a corresponding change in extension. The splint, of course, is unsuitable for transport.

(3) **The Fixed Wire Cradle Splint.**—Hey Groves originally introduced this modification of the Hodgen splint, and lately he has considerably modified the original model. The splint is made in two sizes, one having a longer thigh section than the other, and intended for use in fractures of the upper third

of the femur. The splint is made throughout of metal, the frame being of $\frac{1}{4}$-inch steel wire and the base of $\frac{3}{4}$-inch flat steel. The base is a long parallelogram with a swivelled cross piece to prevent rocking. To the base the frame is

FIG. 20.—Hodgen's wire cradle splint.

attached by three uprights on each side. The splints are so made that they pack in nests together.

The splint is prepared for use by slinging double strips of flannel or rubber bandage across from side to side; the leg is lifted off the bed, using traction on the thigh, and laid upon the cradle, the knee being bent over the angle of the splint.

There is a foot-piece with two outstanding metal bars which

prevent the foot from rolling laterally, while not interfering with extension.

The mere bending of the knee over the double inclined plane of the splint serves to maintain a certain degree of traction force, and this may be made still more efficient by making the first sling below the knee of rubber.

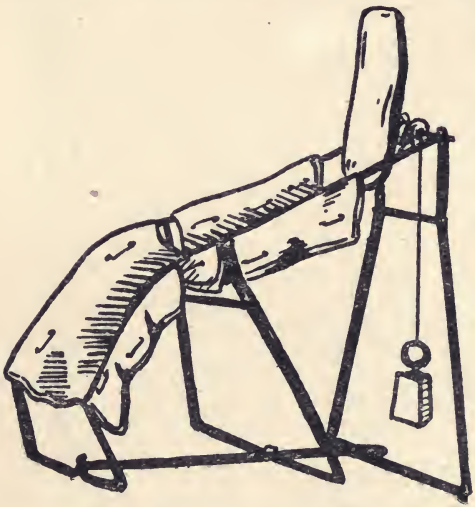


Fig. 21.—The fixed wire cradle splint.

If this is not sufficient, ordinary extension may be applied to the thigh if the knee is kept flexed—or to the whole limb if the knee is extended.

A special metal leg cradle may be used for extension; it is fastened to the upper part of the calf by a bandage and is provided with two metal eyes which serve for attachment of the extension cord.

The extension cord is carried over an elevated pulley at the lower end of the splint, and a suitable weight attached. If it is desired, transfixion extension is easily adapted to the splint. This is probably the best of all the angled splints in use; it is self-contained and can be used to transport. But it must be remembered that the position of flexion of the thigh entails the risk of encouraging pus to track up the limb.

(*C*) **Special Splints for use in Fractures of the Extremities of the Femur.**—Compound fractures of the neck of the femur

and all fractures about the small trochanter should be treated in the abducted position. If this is not done, union is apt to occur in an adducted position, and a deformity of the coxa vara type will result. To prevent this, it is necessary to secure abduction and to maintain extension in the abducted position. Owing to the position of the soft tissue wound, it is rarely that one can use a splint with a thigh ring, such as the Thomas.

(1) *Abduction Frame.*—If the wound or wounds are on the anterior, lateral, or medial aspects of the thigh, a Jones abduction frame is an excellent splint to use. It is made somewhat after the principle of a double Thomas hip splint, one or other limb of the splint being so made that it can be abducted to a varying angle. The splint extends from around the chest below the axillae to some distance beyond the feet.

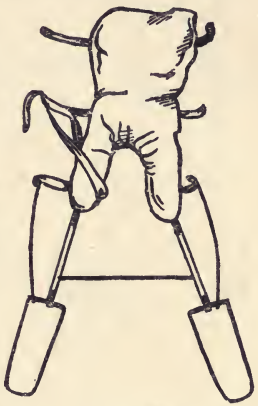


FIG. 22.—The abduction frame splint. (Jones.)

Extension is applied to the affected limb, and the ends of the extension are fastened to the extremity of the splint or to a weight and pulley. Counter extension is obtained by a padded strap which passes round the perineum and is fastened to one of the body wings on the opposite side.

If the wound lies high up at the back of the thigh or in the buttock, the problem of splintage becomes exceedingly difficult.

(2) *Hodges Cradle.*—Hodges [1] has described a splint which is sometimes useful in these cases. The splint consists of an iron cradle which is passed round the patient at about the level of the umbilicus. At right angles to the cradle is attached a second cradle which passes vertically between the patient's

[1] Hodges, *British Medical Journal*, March 13, 1917, p. 423.

thighs. To this again are fixed (1) a cross bar to give support when the apparatus is on a stretcher, and (2) a modified form of Thomas's leg splint supported at the foot end by a folding upright. The leg splint is attached to the transverse cradle on the outer side by a short bar adjustable as to length, and to the second cradle by a slotted bracket and thumb screw. A stout canvas sling is attached to the transverse cradle by straps and buckles, and suspends the patient's lumbar region and perhaps just the upper part of the sacrum. A second sling is attached to the second cradle and to the outer adjustable bar, to take the weight of the thigh just below the natal fold. A third sling is fixed to the leg splint near the foot. The head, shoulders, and opposite leg being suitably supported, the patient can be raised by means of these slings six inches or more above the bed.

FIG. 23.—The abduction frame splint interrupted opposite the left hip on account of a wound in this position.

For hospital treatment of this type of case the wire cradle splint already described often answers quite well. The cradle, as a whole, requires to be set at a higher angle so as to hold the leg up and expose the buttock for dressing or drainage.

Full weight extension and abduction are important to prevent the possibility of subsequent coxa vara.

Double Fractured Femur.

These are very dreadful injuries, and only very few survive the original shock. Their treatment is extremely difficult. They cannot be treated by any of the splints with thigh rings, as the rings overlap the perineum.

They may be treated by separate Hodgen's or fixed wire cradle splints, but with these, nursing is extremely difficult.

Undoubtedly the best splint for such cases is the Jones double abduction frame. When efficient extension is applied, the limbs are completely immobilised, and the patient can be easily turned or lifted for nursing purposes.

When both limbs are abducted, the splint takes up a great deal of room, and for this reason it is not very suitable for transport. Therefore for transport of these cases it is better to use a light wooden or canvas and wood framework. A reclining body-rest is formed of three planes: the upper is about three feet long and supports the body at an angle of

FIG. 24.—Frame for transport of cases of double fracture of the femur. (Hey Groves.)

30 degrees; the middle one, inclined in an opposite direction, is 12 inches long and lies under the thighs; whilst the lower of 18 inches supports the legs. The section below the thighs is so arranged that it is removable, and so dressing or nursing is facilitated. (Hey Groves.)

The whole frame can be strapped on to a stretcher or laid in a cot or bunk.

Fractures of the Tibia and Fibula.

Gunshot injuries of the bones of the leg present certain special features.

Comminution is the rule, and the more simple types of fracture the exception. Owing to the superficial position of the

tibia, access is generally easy. The posterior tibial vessels are very liable to damage, and their injury is frequently followed by grave consequences to the vitality of the limb. The replacement of the fragments is generally easy. There is a feature which appears late in the history of these cases and does not concern us here: it is this, that non-union or delayed union is a complication which occurs more frequently after gunshot wound of the tibia than in any other long bone. The reason for this is probably the comparative avascularity of the lower fragment with subsequent sclerosis and delayed callus formation.

The general principles of treatment of these cases are similar to those we have already outlined. More detailed attention must be given to the varieties of splint which are suitable in the treatment of this injury.

Of the straight splints, the Thomas knee splint, the Wallace-Maybury, and the Page splint are all suitable. They are applied in the method we have described, with some differences in the methods of extension which are described later.

The Wire Cradle splint described above for the femur is suitable for fractures below the knee, but it is unnecessarily bulky. A smaller splint which only goes a short distance above the knee-joint is well suited both for hospital use and for transport. The knee is held semi-flexed, and across the broadly curved upper angle of the splint a transverse padded band holds the popliteal region of the thigh and affords counter extension. The leg below the knee is inclined downwards so that gravity aids extension. Extension is arranged in one of the ways we shall describe.

Sinclair's Ankle Splint.[1]—When the fracture involves the extreme lower ends of the bones, with possible injury to the ankle-joint, a splint devised by Major Sinclair is of value. It

[1] Sinclair, *B.M.J.*, Feb. 5, 1916, p. 197.

is made out of the aluminium splinting from the Field Service fracture box in the following way :

A length of aluminium of 40 inches is bent on its edge at a third of its distance from the lower end to an angle of 40 degrees. At the junction of upper and middle thirds it is bent to an angle of 130 degrees, and about 2 inches from the upper end it is bent on the flat to an angle of 45 degrees. Another length of 40 inches is bent in a similar way. These

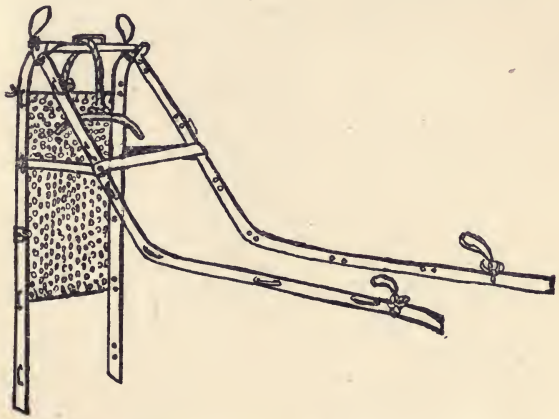


FIG. 25.—Sinclair's splint for compound fracture of the ankle joint.

two pieces are riveted together 6 inches apart opposite the lower bend and again about 3 or 4 inches from the lower end. The transverse bar opposite the lower bend has a staple in the centre from which the foot is suspended. From the lower bend downwards to the lower end of the splint a sheet of perforated zinc is fastened in position by means of wire, and against this sheet the foot rests. The lower bend of the splint is reinforced by a thin strip of aluminium which passes around the three sides of the bend but not across the sole.

The upper ends of the splint are fastened to the leg below

the knee by a plaster bandage. A cotton sock is placed on the foot and cut obliquely from the heel to the middle of the instep. To the staple we have already mentioned a cord is attached, and from the cord a small arc of aluminium four inches long is suspended. The arc is placed inside the toe of the sock, the cord passing through a hole in the sock. The

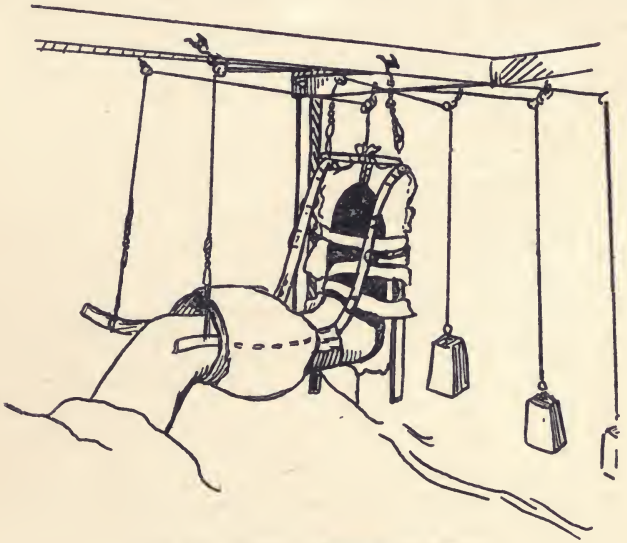


FIG. 26.—Sinclair's ankle splint applied.

sock is applied dry and its outside is painted with a solution of equal parts of Canada balsam in xylol, Venice turpentine, and ether.

The aluminium arc acts as a suspending spreader for the foot, and it is fastened in place by the sock: it is suspended by the cord. A layer of cotton wool is placed between the foot and the perforated zinc, and the foot is fastened in position with bands of adhesive plaster.

When the splint is in position it is suspended from an over-

head supporting bar. It is a comfortable splint, and it affords ready access for dressing.

Methods of applying Extension in Fractures of both Bones.—It is possible that extension may be applied in one of the methods we have already described, that is by means of adhesive plaster, or by glueing gauze, or Canton flannel, to the sides of the limb. Very often, however, the wounds are multiple, and it is impossible to ensheathe the limb in the extension material. If the foot should happen to be involved with wounds, then it is necessary to use some form of transfixion extension. A transfixion pin may be driven through the os calcis or through the malleoli, or, as we have sometimes used it, through the soft tissues immediately above the os calcis and in front of the tendo Achillis. Hey Groves' screw clamps may be used, being fastened either to the malleoli or to the os calcis.

Lately we have used Finochietto's horse-shoe spring apparatus, inserting it through the soft tissues in front of the tendo Achillis. To the ends of the pins or clamps, extension is applied in one of the usual ways. If the foot should be free from wounds, and it is not desirable to use any form of transfixion extension, there are several ingenious devices, any one of which may be used. Most of these methods we owe to the ingenuity of Major Sinclair.

Method 1.—The foot extension is applied by means of ¾-inch strips of flannel bandage, each strip being threaded through two metal triangles or rings. One set of 6 triangles is aligned along the inner margin, another set of 6 along the outer margin of the sole. The flannel strips are glued to the sole, sides, and dorsum of the foot, care being taken that the ends do not meet over the dorsum. Cotton wool is dabbed over the glued area to hasten and strengthen the setting.

The triangles or rings are threaded with tapes which are passed over the serrated edge of a wooden foot-piece and tied.

The foot being now secured to the foot-piece is commanded absolutely. On the under surface of the foot-piece there is a transverse bar to which the extension tapes are attached.

Method 2.—A plaster cast is made of the sole of the foot by means of flannel impregnated with plaster of Paris. Incorporated in this cast are tapes. When the cast is dry it is glued to the sole of the foot, and extension is obtained by attaching it with the tapes over the serrated border of the special foot-piece.

Method 3.—A padded wooden foot-piece is applied to the sole. A large fitting sock is pulled over the foot and foot-piece.

The outside of the sock is painted with a solution of equal parts of Canada balsam in xylol, Venice turpentine, and ether. When this has dried, a screw ring is screwed into the wooden sole, and from this extension is carried. The sock can be cut away to any level around the ankle.

Method 4.—A shoe is made for the foot, the sole of wood and the upper of loose soft leather. The leather is laced across the instep and extension is taken from the wooden sole.

The Importance of the Position of the Foot-piece in low Fractures of the Leg Bones.—The lateral position of the foot, *i.e.* as regards inversion or eversion, must be carefully guarded. A slightly inverted position is to be aimed at, so as to avoid the common tendency to talipes valgus. The lateral traction to produce the correct degree of inversion is provided by having the extension attachment to the sole piece, to one side or the other of the mid-line.

The position of the foot as regards plantar or dorsiflexion is important. The fixation of the foot-piece at right angles to the leg portion is an uncomfortable position. It causes increased tension on the calf muscles. Under most conditions the foot-piece should be inclined at an angle of 120 degrees to the line of the limb. This relaxes the posterior calf muscles, and is at the same time a comfortable position.

Compound Fracture of the Foot.

Gunshot injuries of the foot are either in the nature of perforating bullet wounds without much infection or bone destruction, or badly shattered shell wounds in which there is much comminution and infection. The former require no active treatment—simple dressing is sufficient. Compound comminuted fractures of the tarsus are most dangerous and should receive special attention, the infected tracks through the bone being carefully excised.

If the astragalus is severely damaged it is especially important to remove it, otherwise ankylosis of the ankle-joint will most likely occur. There are two bones of the foot which should be preserved at all cost, the os calcis and the first metatarsal bone. They form the chief base of support for the body in standing, and to them the most important musculatures are attached.

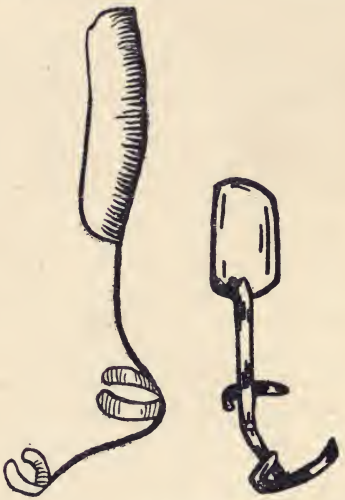


FIG. 27. — Crab splints for use in compound fractures of the foot and leg.

Splints to be used in Compound Fractures of the Foot.—Jones's rectangular splint, sometimes called the *crab* splint, is undoubtedly the best for all general purposes.

It affords easy access for dressing and the foot-piece can be adjusted to any desired position.

Sinclair's Net Frame Suspension for Treatment of Compound Fractures of the Lower Limb.—This method finds its

greatest sphere of usefulness in base hospitals, but there is no reason why it should not be applied in some measure in Casualty Clearing Station work. It is of great value in the treatment of compound fracture of the femur; it may also be employed in compound fractures below the knee. It is an ingenious combination of the hammock with abduction of the thigh embodying the principle of Hodgen's thigh splint.

A wooden frame 7 feet by 5 feet is constructed with a transverse bar which is opposite the position of the patient's umbilicus. Two leg bars run from the umbilical bar to the foot of the frame. Extension is applied to both legs, and the extension cords are passed through holes at the end of the frame and tied. The patient's back and legs are well padded, and the body and the legs are supported in the frame by strong thick netting. This netting is in three pieces, one for the body, fixed to the sides and head of the frame, and two leg pieces fixed to the leg bars which are abducted to the necessary angle. Either can be freed independently. The frame is slung by the corners to four uprights (the universal leg suspension frame). Extension is obtained by lowering the head of the frame about 15 inches.

This method of treatment is efficient, and the results are very satisfactory, both dressing of wounds and nursing of patient being extremely simple.

Compound Fracture of the Upper Limb.

Fracture of the Humerus. — We may consider these fractures under three headings—according as to whether the upper end, the shaft, or the lower end of the bone is involved.

Upper End.—When the head of the bone and the tuberosities are shattered, it is most likely that the shoulder-joint is also involved. Wounds of this type are

associated with a very considerable amount of shock. The wounds are treated on the principles already laid down. If the shoulder-joint is involved and there is much comminution of the head of the bone, it is advisable to remove the head entirely. The most careful toilet of the wound is carried out, all obviously infected tissue being removed. The axillary (circumflex) nerve is frequently injured, and the damaged ends should be sutured now. Even if union with primary regeneration can scarcely be expected to occur, it is wise to bring the ends together at this early stage; future neurorrhaphy is greatly facilitated thereby.

As regards the further treatment of the wound, the majority of compound fractures of the upper extremity may be dealt with by primary suture—a depôt antiseptic may or may not be applied.

Splints. — Any splint may be used which permits free access to the wound and at the same time keeps the arm abducted from the side to half a right angle. The position of abduction is important because, if ankylosis occurs, this position ensures the greatest degree of usefulness to the limb. Middeldorpf's splint or one of its modifications is probably the best splint to use. It is a double inclined plane, the base of which is fixed to the patient's side, while the injured arm rests on the other two sides of the triangle. Middeldorpf's original model is bad because it necessitates that the forearm be held in a pronated position. If no ready-made splint is available, a wedge-shaped splint of poroplaster or zinc can easily be made which answers the purpose admirably.

It is unnecessary to apply extension, as the weight and position of the arm ensures this.

The position and nature of the fracture may be such that primary excision of the shoulder-joint is necessary.

The results up to the present have not been good, and there is a feeling that conservatism should be persevered in when possible. If excision must be done the upper end of the lower fragment should be kept well up to the glenoid, in order to favour ankylosis and so get those scapulo-humeral movements which are essential for good functional results. The best splint for this purpose, though perhaps hardly applicable to Casualty Clearing Station work, is that used by Sir Robert Jones, consisting of a body girdle and a movable arm-piece.

In Clearing Station work it is often necessary to keep the wound open for drainage purposes, but if primary closure has been done the above-mentioned splint (Jones's) should be used.

Shaft of Humerus. — Gunshot fractures of the shaft generally display marked comminution. Paralysis of the radial (musculo-spiral) nerve occurs very commonly, though it is often only temporary, as the result of contusion and not actual severance of the nerve.

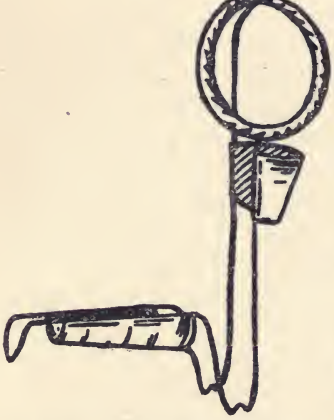


FIG. 28.—Jones's angular splint for compound fracture of the humerus.

If it should be found that the nerve is divided, immediate suture should be done.

Splints. — A number of these fractures have been treated without any splint at all, or with a mere protective splint incorporated in the dressing.

If primary closure of the wound has been carried out, it is advisable to apply some more effective splinting. In many cases a simple rectangular splint answers the purpose: Clarke's pattern is the best.

When there is much displacement of fragments, and it is necessary to apply extension, there are several varieties of splints which may be used.

Fig. 29.—Straight arm splint of the Thomas pattern.

The two varieties of Jones's angular splints give good results. In one, shoulder fixation is taken by means of a ring; in the other, by means of an axillary crutch. The second variety is useful when there is an extensive wound on the outer aspect of the arm.

A favourite splint is Thomas's straight splint modified for the arm. It is very much after the model of a miniature Thomas knee splint. A movable bar at the lower end is adapted so that it is grasped by the patient's hand, and the ring at the upper end takes its fixation around the shoulder. Extension is applied to the forearm and secured to the lower end of the splint.

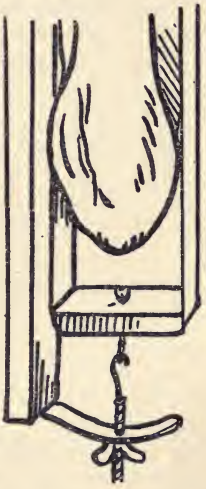


Fig. 30.—The modified Borchgrevink splint. (Hey Groves.)

Until recently this splint had the disadvantage that it was unsuitable for transport, because it entailed keeping the arm abducted to a right angle, and to bring the arm down to the side meant a readjustment of the extension. This difficulty has been largely overcome by jointing the lateral bars to the ring so that adduction of the arm for transport is possible.

The last variety of splint which may be mentioned in this

situation is the Borchgrevink splint, or one of its modifications. A Y-shaped splint with a padded crutch is applied to the inner side of the arm—the crutch resting against the axilla.

Extension is applied to the inner and outer aspects of the arm, and is attached to a little wooden stirrup below the elbow. To the lower end of the internal straight splint a projecting metal spring is attached; the spring and the stirrup are connected with a winged nut and screw, and by adjustment of this extension can be secured.

Lower end of Humerus.—These injuries are constantly associated with injuries to the elbow-joint. In treatment of them one must keep in view the possibility that ankylosis of the elbow-joint may occur.

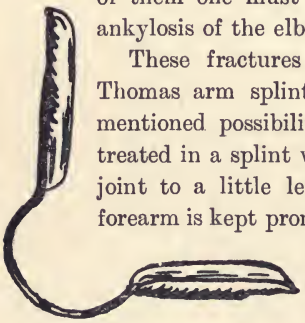


FIG. 31.—A variety of crab splint for use in compound fracture of the elbow-joint.

These fractures are often treated in a straight Thomas arm splint, but with regard to the above-mentioned possibility we believe that they are better treated in a splint which secures flexion of the elbow-joint to a little less than a right angle, while the forearm is kept pronated. For this purpose a modification of the crab splint is excellent. The upper part of the splint is attached to the back of the upper arm, the lower part is fastened to the forearm, and the two pieces are connected by a hoop of malleable iron. This leaves the injured parts free for observation and dressing, while any reasonable adjustment of the position of the arm can be carried out.

Fractures of the Forearm.—It is unnecessary to say much about these cases. One caution is necessary, and that is to avoid persistent pronation of the hand when the fracture is splinted. If pronation is maintained, ankylosis may occur between the radius and ulna in this position, and the power of supination is lost.

To maintain the forearm supinated while the elbow is kept flexed means a very irksome position; it is therefore better to treat these fractures in the fully extended position with a Thomas arm splint, the forearm being supinated.

Extension may be applied to the forearm by any of the above-mentioned methods. Sometimes a little metal frame handpiece is used. It consists of an oval which passes round the hand opposite the middle of the metacarpus, and a stirrup at right angles to this which is of a size to surround the edges and tips of the four fingers. Adhesive strapping is attached to the encircling oval, and the extension force to the horse-shoe loop. In this way fingers and thumb are free and can be exercised at will.

Fractures of the Metacarpals and Phalanges.—In the most of these cases no special splinting is required. If much displacement has occurred and is persisting, it may be advisable to use some form of extension apparatus.

Hey Groves has suggested a method which is satisfactory. A wood splint is fixed to the forearm. To its edges is attached a metal band which is of a size and shape to encircle the periphery of the outstretched digits. Five holes in this metal band afford traction points for as many springs which can be adjusted by screws. Extension is attached to the plantar and dorsal surfaces of the fingers, and by means of small wooden stirrups the extension is fastened to the screw. Sinclair uses a good apparatus in which the fingers of cotton gloves fastened to the digits with glue are used to apply extension.

Fractures of the Clavicle. — These are treated on the general lines already laid down. There are one or two special features to which attention ought to be drawn.

If there is much comminution of the bone, the injured portion should be removed. The entire bone can be excised with little or no injury to the arm. If the bone is not removed as accurate apposition as possible should be obtained, because

there is a danger of excessive callus formation with resulting pressure upon the brachial plexus.

In the after-treatment of the wound all that is necessary is to keep the arm in a sling.

Fracture of the Jaw.—In the Casualty Clearing Station the treatment of these cases should be limited to a thorough toilet of the wound, and to the keeping clean of the mouth by means of antiseptic mouth washes. Special hospitals are now provided for the treatment of these cases, and any radical interference in the Casualty Clearing Station is inadvisable.

If the lower jaw has been largely destroyed, it may be necessary to perform a tracheotomy or a laryngotomy.

Fracture of the Patella.—Compound fractures of the patella are dealt with in the Chapter on "Wounds of the Knee-Joint."

Fracture of Scapula.—These may prove to be very troublesome cases; they are often complicated by penetration of the chest. Haemorrhage is severe, and dangerous infection is liable to occur.

They are treated by complete exposure of the damaged bone, by removal of all detached and infected bone, and if possible by closure of the wound with or without the use of a depôt antiseptic.

CHAPTER VI

WOUNDS OF JOINTS

Wounds are met with affecting any of the joints of the body, but wounds of the knee-joint have hitherto demanded the largest amount of attention. There are several reasons for this. The knee is more commonly wounded than any other joint. Following a wound of this joint there is always a possibility that locomotion may be interfered with. If severe infection of the joint occurs, there is considerable danger to the limb and even to the patient's life. The internal anatomy of the knee is such that suitable treatment is often rendered difficult.

We propose to take up in detail the treatment of wounds of the knee-joint, afterwards discussing any special points which may arise in connection with wounds of the other joints.

Wounds of the Knee-Joint.

Type of Missile.—It is important to find out the type of missile which has caused the injury. The wound caused by an undeflected rifle bullet is likely to be less serious than that caused by irregular fragments of shell or bomb. The latter cause more destruction and are more likely to be followed by serious infection.

Early Treatment.—Apart from the application of the first

field dressing, it is most important that these wounds should be splinted when first seen. Movement may aggravate infection already present; it may facilitate infection of a joint hitherto uninfected; and it may very easily lead to the displacement of a foreign body from a situation easily accessible to a position of inaccessibility.

Treatment on Arrival at Casualty Clearing Station.—The original dressing and splint are removed as soon as possible after admission of the patient, and certain important details are noted:

1. The patient's general condition. It is possible that there are evidences of shock, haemorrhage, or septic infection.

2. If possible, the exact date and time at which the injury was received.

3. The nature of the wound: whether a penetrating, perforating, or open wound, and the exact sites of the entrance and exit wounds. Some evidences may be obtained as to whether or not a fracture is present.

4. The presence of effusion into or about the joint. It is important to determine whether the effusion is actually into the joint or not.

5. The presence of other wounds of the limb above or below the joint.

6. The condition of the pulse and temperature.

Having satisfied oneself on these points, the splint is replaced in position and the joint is X-rayed in two planes, one at right angles to the other.

If there is effusion into the joint, it is well at the same time to drain off some fluid from the joint with a fine hollow needle. The fluid is sent for an immediate bacteriological examination in film, and for a later report on culture. The first report can be received while the radiographs are being taken, and its nature may influence the subsequent operative treatment.

Classification of Cases.—The clinical examination and the result of the X-ray examination will enable the surgeon to classify the case; and it will naturally fall into one of the following classes:

A. No bone injury and no projectile included.
B. No bone injury but projectile included.
C. Bone injury—no projectile included.
D. Bone injury—projectile included.
E. Extensive bone injury of such gravity that involvement of the joint is only of secondary importance.

Prognosis of Cases.—The presence or absence of injury to the bone is the most important deciding factor in the final result. In Classes *A* and *B*, where no bone injury is present, and given a joint in which suppuration does not occur, a good movable knee is generally obtainable.

In Classes *C* and *D* the result will vary from complete mobility to absolute ankylosis, depending upon the amount of injury of the bone which is present.

In Class *E* no functional result is possible, and the saving of life, and, if possible, of the limb, is the only consideration.

The second factor which influences the prognosis is the degree of infection present when the case comes under treatment. Efficient operative measures, however, have largely overcome this factor.

Operative Measures.—I. In Classes A and B—no Fracture present.

Preparation of Case.—The splint is not removed until the patient is under the influence of the anaesthetic.

The skin is carefully shaved for six to eight inches above and below the knee, and the skin surface is cleaned with fluid soap followed by spirit and painted with iodine. The knee is partially flexed and rested in this position on a sandbag. Colonel Gray recommends placing the knee in the position in which it was supposed to be when the injury

was sustained; this will tend to make the wound track a continuous one.

Operation. — The first step is the excision *in toto* of the wound or wounds down to the capsule. This is done with sharp knife and forceps. The wound, if possible, is not opened into, but is excised *en masse.* Clipping infected tissue away piecemeal courts disaster.

With a fresh knife and forceps the edges of the wound in the capsule and in the synovial membrane are excised.

Instruments, towels, and gloves are now changed so that there may be no possibility of infecting the joint cavity. With fresh instruments the wound in the capsule is enlarged sufficiently to gain access to the joint. Any blood clot lying in the joint is cleared out, and this is best done by a stream of warm saline or eusol. A careful search is made for any pieces of clothing which may have been carried into the joint, and if a foreign body is present it is removed.

If the projectile is far from the entrance wound, it often saves injurious handling after excising the track to enter the joint through a fresh incision which is sutured completely as soon as its purpose has been served. A considerable quantity of fluid should be used in the irrigation—about two pints—and while the irrigation is being carried on, the limb is being gently flexed and extended. A more efficient lavage is thus secured.

The gap in the synovial membrane and capsule is closed with interrupted sutures of fine catgut. If possible synovial membrane and capsule are closed separately.

A small tube is left down to but not into the capsule, and, if necessary, the tissues about it are closed with catgut. The skin wound is approximated with interrupted silkworm-gut sutures. Stress must be laid on the necessity of closing the wound even at the expense of a flap of muscle, fasciae, or even skin.

The wound is covered with a gauze pad, and a thick wool

dressing is applied with a firm roller bandage. It has been recommended to place a pad of wool in the popliteal space, as this tends to prevent effusion passing into the posterior recesses of the joint. The limb is placed on a splint before the patient comes out of the anaesthetic. The different varieties of splints are discussed later.

II. **In Classes C and D—Fracture present.**—Such a wound is treated in exactly the same way as described above. If a foreign body is present it is removed. All loose fragments of bone are taken away and all soft, bruised, and possibly infected medulla is removed. Haemorrhage from the bone is arrested by packing for a few minutes with gauze soaked in 5 per cent picric acid in spirit. If at all possible, the wound in the synovial membrane should be closed. When the wound is extensive this may be difficult, but if the synovial membrane around is undercut and separated from its attachment with a pair of curved scissors, closure can generally be effected.

If possible, too, the wound in the capsule should be sutured. Sometimes the wound in the bone is so placed that when the capsule is closed the joint may be isolated from the bone wound. This should be done whenever possible. Frequently, however, it is impossible to close the wound in the capsule completely. It is then approximated as much as possible, and the gap is loosely packed with gauze wrung out of saline or eusol. A firm gauze and wool dressing is applied as before, and a splint is put on.

Difficulties which may arise in the course of the Operation.—One of the greatest difficulties is the closure of the gap in the synovial membrane. When, for example, it has been necessary to remove the patella, on account of comminution of the bone, the difficulty becomes a very real one. It is overcome by loosening the attachments of the surrounding synovial membrane, and so mobilising it that it can be used to repair the

gap. In dealing with the gap left by the patella, one uses the large supra-patellar pouch for this purpose, and the principle can be applied to any part of the joint.

Similar difficulties may be met with in attempts at closure of gaps in the capsule, and when it is essential that the wound be closed, a flap can generally be planned which fills in the space.

III. **Operation on Cases in Class E.**—In this group there are two methods of procedure which may be called for—excision and amputation.

Excision.—If in less severe cases the opposing ends of the bones are so comminuted that smooth articular surfaces are not available, primary excision is indicated.

Free access is obtained to the joint. An incision may be planned which connects the entrance and exit wounds. We generally employ a curved incision convex downwards passing below the patella and dividing the ligamentum patellae. The internal and external lateral ligaments are divided, and the crucial ligaments are cut across. The joint is fully flexed, exposing the entire articular surfaces of femur and tibia. The semi-lunar cartilages are removed in their entirety. The damaged articular surface or surfaces are removed with a bow saw. Even if only one articular surface is damaged, it is advisable to remove with as thin a scale of bone as possible the opposing articular surface. If this is not done, necrosis of the cartilage will most probably occur. The amount of bone excised will depend upon the extent of the osseous damage. It is possible that one condyle has been severely comminuted, while the other is uninjured. A block excision of the damaged condyle should then be done, thin articular scales being meantime removed from the surface of the other condyle and from the head of the tibia.

Damage to the articular surface of the tibia is more serious than a corresponding amount of damage to the lower end of

the femur, and if the comminution of the tibia is extensive, amputation is generally necessary.

When the excision is completed, the limb is put up in a Thomas or Page splint with extension. There are some who advise that after the excision the raw bone surfaces may be allowed to come into contact at once. We believe, however, that it is better to maintain a space between the excised surfaces by extension for some days. If the patella has been shattered it is removed, but if the bone is uninjured it is better left *in situ*. The space between the bones is loosely packed with gauze wrung out of saline or eusol. The packing is left in position for four or five days, and if the temperature chart is then favourable the bone surfaces are allowed to come into contact, and a few days later the edges of the capsule are approximated and the skin wound closed. Plaster is then the best method of immobilisation.

Amputation.—If the injury has implicated the main vessels so that the foot is already cold, amputation should be done, just above the knee if the wound is likely to remain uninfected, and through the knee if sepsis is present and the condyles are undamaged.

If the popliteal nerves are damaged beyond all hope of repair immediate amputation is advisable.

When the head of the tibia is severely comminuted, it is probably better to amputate at once. If sepsis is already well established, especially if there be gas gangrene and the patient is in low condition from haemorrhage or toxic absorption, amputation must be done.

There are certain cases which, while they cannot be classified under groups *C*, *D*, or *E*, yet may be included as wounds of the knee-joint. These are cases in which a foreign body has become lodged in the condyle or in the head of the tibia, and one or more fissured fractures have extended into the knee-joint.

An X-ray examination will demonstrate the position of the fragment, and the route of access to the fragment will depend upon its position. If possible the foreign body should be exposed without opening the knee-joint; with chisel and curette the fragment and its infected track are removed. In certain cases it may be necessary to open the joint in order to gain access to the metal. All bruised and infected bone is removed together with the missile; it may be necessary to sacrifice a considerable portion of one condyle or tuberosity. The joint is afterwards closed. This type of case often yields excellent results.

The Treatment of Established Infection of the Joint.—It is inevitable that a certain proportion of cases arrive at the Casualty Clearing Station with severe infection of the joint already well established—cases which have lain out in the open for some time, or which, from the exigencies of the military situation, have failed to receive early attention.

The general condition of the patient shows signs of the sepsis which is present—the temperature is elevated and the pulse rate increased. Locally the joint is swollen and inflamed; it is held in a semi-flexed position, and from the wounds of entrance or exit a seropurulent discharge is escaping. These cases form a distinctive group and call for distinctive treatment. In many cases, where there is the complication of serious bone injury, immediate amputation is often the only course if life is to be saved.

The majority of these cases, however, offer an opportunity for more conservative measures. The synovial membrane shows a remarkable resistance to infection, and given reasonable assistance it frequently succeeds in overcoming it.

Ordinary tube drainage of the joint on classical lines has not proved a success. The exposure of the joint surface by a transverse section and fixation in full flexion still has its advocates, but the method has given poor results. Fullerton

has suggested formal excision of the joint at this stage, but it seems unwise to open up an extensive new surface in the presence of a progressive infection, while experience shows that a certain proportion of cases recover, even after a generalised infection with pus formation, without such drastic measures being resorted to.

To begin with, an opportunity should be given to the joint to overcome the infection by natural resistance. Certain things are done which will assist in the resistance. The wounds of entrance and exit are excised down to and including the capsule and the synovial membrane. The joint is kept at absolute rest in a Thomas or Page splint, and extension is applied; this fixation is probably the most effective part of the treatment. Special care should be taken to prevent movement of the joint during dressing of the wound. If there is much tension of fluid in the joint, arthrotomy is performed by two vertical parallel incisions into the most lateral parts of the subcrural pouch; the arthrotomy incisions are lightly packed with gauze down to but not penetrating into the joint cavity. Campbell recommends that the seriously infected joint be drained posteriorly. This he achieves by inserting the closed blades of a forceps through the anterior incisions by the lateral and median aspects of the condyles into the posterior pouches of the synovial membrane. The blades of the forceps are cut down on posteriorly and drainage tubes guided into position.

If this method is given an efficient trial, it will be found that in a certain number of cases the temperature will settle and the joint swelling will subside.

Even though the man's symptoms are subsiding, a careful watch should be kept for the development of secondary abscesses around the joint; they are most apt to appear in relation to the bursae of the popliteus and semi-membranosus muscles.

If such conservative means fail in their object, we resort to irrigation of the joint by Carrel's method.

The incisions already made into the joint are enlarged, or others more suitable are planned. The instillation tubes are carried into the various recesses of the joint, and irrigation with eusol or Dakin's solution is begun. The limb is meantime carefully splinted with suitable extension.

If success still fails to attend these efforts, treatment by excision or by amputation must be considered.

Fig. 32.—Hepburn's splint.

The Application of Splints.—We have always employed a Thomas knee splint or a Page splint in the after-treatment of these cases. If much infection of the joint is present, if there is persistent pain, or if there is a tendency for the joint to become flexed, we apply a suitable extension.

By those who choose to treat the infected knee-joint in a flexed position Hepburn's splint is preferred. It is an aluminium splint moulded to the leg and thigh, flexed at the knee to slightly less than a right angle, and provided with a foot-piece.

The old-fashioned posterior "ham" splint is still a favourite with some. It complicates dressing, however, and extension with it is difficult. In cases of wounds of the joints in which the bone has been uninjured it is desirable to begin early movement of the part. Active movement should be begun not less than seven days after suture.

Retention of Cases after Operation.—Cases which have been operated on should be retained in the Casualty Clearing Station for at least forty-eight hours. If there is no immediate demand for their evacuation, it is advisable to keep them under one's care for five to seven days.

The Thomas and the Page splints are excellent for transport. Firm compression of the joint with a large pad of cotton wool and a roller bandage is a most important preliminary to evacuation. A narrow fold triangular bandage should be passed round the bars of the splint in front of the knee.

Gunshot Injuries of the Elbow-Joint.

These may be considered next in importance to wounds of the knee-joint. The injury is a common one. If injury to the bone is at all extensive ankylosis is very likely to occur, though as a matter of fact there have been a great number of flail limbs. If ankylosis occurs, and more especially if it occurs with the joint in an unfavourable position, the usefulness of the arm is greatly interfered with.

Slight Wounds.—If the wounds are slight and there is not much injury to the bones, it is sufficient to excise the wounds, to remove the foreign body, if such is present, to close the wounds, and to put the arm up in a simple splint which holds the arm flexed to a little less than a right angle with the forearm semi-pronated. If ankylosis should occur, this is the best position the arm could occupy. We have found a "crab" splint the most suitable appliance to employ. The angle of favourable ankylosis depends on the man's occupation; a clerk is best with the elbow at about the right angle, the labourer with a slightly flexed elbow.

More Severe Cases.—If the damage to the elbow-joint is complicated by comminution of the articular ends of the bones forming the joint, the wisest course undoubtedly is to perform a primary excision of the joint. Kocher's external J-shaped incision affords the best access. As regards the amount of bone which should be removed, it is necessary to cut one's coat to the cloth. If one articular surface can be left intact so much the better, and this is especially applicable to the

upper end of radius and ulna; the best results are obtained when the articular ends of these bones can be left intact. In performing the excision, muscular attachments should be interfered with as little as possible. Conservative resection is important, otherwise a flail limb is likely to occur. After excision, the cavity is irrigated with saline or eusol, and the wound closed on the principles already laid down in connection with the knee-joint. If the wound has to be left open the straight Thomas arm splint is best until the wound is clean. Afterwards the elbow is flexed to the appropriate position and a right-angled splint applied. As soon as the wound is healed the splint is removed and the arm is supported in a sling, the patient being encouraged from the first to use his hand and fingers.

Severe Sepsis of the Elbow-Joint.—In these cases which come under treatment with an infection already well established, it is proper to at once perform a complete excision of the joint, both articular surfaces being removed.

Experience shows that the free drainage immediately provided is coincident with a rapid fall in pulse and temperature, and the patient makes rapid strides towards recovery. In this event, it is unwise to close the wound; the cavity is tightly packed with eusol gauze, or the Carrel-Dakin treatment is begun. The wound is closed when sepsis has subsided.

Gunshot Wounds of the Hip and Shoulder-Joints.

These are never met with apart from injury to the bone. If the wound is slight, it is sufficient to excise the wound, remove the foreign body, and after closing the wound to immobilise the joint in an abducted position.

When there is much comminution of the head of the femur or of the humerus, the joint should be excised, the damaged head being removed through an anterior incision. Whether

or not the wound is closed primarily will depend upon the amount of sepsis which is present. In both instances the limb is afterwards fixed in an abducted position. For the shoulder-joint we have used a modification of Middeldorpf's splint, and for the hip a Jones abduction frame.

In excision of these joints the resection should be as conservative as possible. Ankylosis is aimed at, a flail limb being avoided at all costs.

FIG. 33.—A variety of crab splint for use in cases of compound fracture in the region of the ankle-joint.

Gunshot Wounds of the Ankle-Joint.

In most of these cases the astragalus is damaged, and if the comminution has been severe it is essential to remove the bone. When possible, it is important to retain intact the joint between the astragalus and the scaphoid: if this can be done, flatfoot is less likely to ensue.

CHAPTER VII

ABDOMINAL WOUNDS

Abdominal Wounds.—This is the first campaign in which perforating wounds of the abdomen have been submitted to operation with a resulting measure of success.

The operative results in previous wars were of the most disappointing nature, and when the present war broke out the expectant treatment was the orthodox one. The expectant treatment was persevered in during the early months of the war, but the mortality was so high that in May 1915 a determined movement was begun to give early operation a widespread and serious trial. The results have more than justified the change. In pre-operation days the total mortality amounted to about 80 per cent, at the present time it amounts to about 60 per cent.

It may be said that apart from the injuries which are necessarily vital, the question of the success or failure of operation depends upon the time which elapses between the receipt of the wound and operation. If a period of six hours or less has elapsed, the chances are in favour of the patient recovering; after this period the position is reversed, and with every hour of delay the chances of recovery grow smaller.

It is the possibility of early submission to operation which has revolutionised the war surgery of the abdomen. There are certain features in the present campaign which have made

early operation more possible than ever before. These are: the stationary character of the fighting-line, the admirable arrangements for the collection and evacuation of the wounded, and the use of motor ambulances as a means of evacuation to the Casualty Clearing Station.

The Relative Frequency of Abdominal Wounds.—It is only when this subject is considered that we discover how comparatively infrequent abdominal wounds are. In an estimation of the wounded admitted to nine Field Ambulances over a period of six months, the proportion of perforating wounds of the abdominal cavity was 1·92 per cent.

The Casualty Clearing Station returns for a similar period amounted to 0·72 per cent. The difference between the Field Ambulance and Clearing Station figures may be accounted for as follows: (1) The Field Ambulance naturally and correctly erred on the side of making the graver diagnosis when the question was in dispute. (2) A certain proportion of the more severe cases died in the Field Ambulances. (3) In the Casualty Clearing Station a better opportunity for diagnosis included certain buttock, thigh, back, and chest wounds as abdominal wounds, while it excluded certain wounds of the parietes which previously had been classified as perforating.

The general effect was to lessen the proportion of abdominal wounds to total wounds.

The Care of the Patient before Arrival at the Casualty Clearing Station.—Under the present system of evacuation the abdominally wounded man is admitted to the Casualty Clearing Station with the least possible delay. From the Advanced Dressing Station of the Field Ambulance he is transmitted directly to the Clearing Station, and any delay there may be in the Advanced Dressing Station is only that which is necessary to ensure that he is as comfortable as he can be, and that he is sufficiently warmed. A reasonable dose of morphia is given, probably when the patient is first seen, in

order to relieve his pain and to allay his mental anxiety. It is important that the amount of morphia given be carefully noted on the man's tally, and that a reasonable dose ($\frac{1}{4}$ grain) be not exceeded. Anything of the nature of solid food is, of course, withheld, but water in moderate amounts is given.

The average time which elapses between the sustaining of the wound and admission to hospital varies from six to ten hours.

Etiological Considerations of Abdominal Wounds.—Major-General Wallace has recorded a table showing the relative frequency of different projectiles in a large number of abdominal wounds.[1] Out of a total of 834 cases, 334 were due to bullet wounds; 284 were the result of shell fragments; 82 were shrapnel bullet wounds, and 134 cases resulted from wounds by fragments of bomb or grenade.

Bullets and fragments of high explosive shell furnish the larger proportion of abdominal wounds. More bullets pass through the body than other projectiles.

Shell fragments are, of course, of all sizes, but the fragments which are the cause of the abdominal wounds which come to operation are generally not more than 1 inch to $1\frac{1}{2}$ inches in the greatest diameter—usually they are a great deal smaller. The irregular outline and ragged edges of the average shell fragment produce extensive damage to the abdominal viscera.

A high proportion of shell fragments are retained in the body, and this is obviously due to the shape of the fragments.

A certain number of wounds are due to shrapnel bullets. The shrapnel shell usually bursts in the air, and the direction of the ball is therefore downwards; about 75 per cent of these missiles are retained in the body.

Bombs and grenades sometimes break into the most extraordinarily small fragments, often no bigger than a large match head.

[1] Lettsomian Lectures: *Transactions of the Medical Society of London*, March 19, 1917. *War Surgery of the Abdomen*, Messrs J. & A. Churchill, 1918.

Each of these fragments may have very considerable velocity, and in the neighbourhood of the explosion a very great penetrating power. With few exceptions these fragments are retained.

The fragments from a trench mortar bomb are thin sharp-edged pieces of metal; their penetrating power is less than that of bomb and grenade fragments, but it is easily sufficient to produce perforation of the abdominal cavity.

Bomb, grenade, and trench mortar wounds are very commonly met with on the back: the reason for this is that the low velocity of the projectile makes it visible as it is passing through the air, and a man instinctively turns his back upon it in attempting to escape before it explodes.

Pathological Considerations.—*General Incidences of Wounds.*—There is little difference between the number of wounds which occur on the front and on the back of the body, but there is a tendency for wounds to collect towards the sides, especially posteriorly. The explanation probably is that while trench parapet and parados affords protection to the front and back, the sides of the body remain exposed to enfilade fire.

Mid-line wounds are comparatively uncommon. From the relation of the spinal column and the great vessels the early mortality is necessarily very high, and the majority succumb before the Casualty Clearing Station is reached.

The position of the wound and the direction of the missile are important. Side-to-side wounds appear to be the most dangerous of the cases which arrive at an operating unit. Buttock and thigh wounds are very deadly, and the combination of thoracic and abdominal wounds is necessarily very fatal. The least serious of all abdominal perforations appear to be wounds which lie above the level of the transpyloric plane. The liver occupies a considerable part of this space, and injury to this organ is necessarily less serious than wounds of the hollow viscera.

The Possibility of the Escape of Viscera in Penetrating

Wounds.—It has long been a debatable point whether a projectile could traverse the abdominal cavity without wounding the hollow viscera. The present extensive adoption of coeliotomy has afforded a proof, and it has shown that the peritoneal cavity may be penetrated and yet no perforation of a hollow viscus occur.

The Possibility of Spontaneous Recovery after Perforation of Hollow Viscera.—It is undoubtedly a fact that certain cases of perforating wounds of the intestine recover without operation. Clinical evidence of this has been obtained during the present campaign.

Individual cases have been reported by Major-General Makins, by Colonel T. R. Elliott and Captain H. Henry, and by Captain Green-Armytage.

One of the most striking cases was noted by Captain G. Bell, R.A.M.C., and the following is a brief outline of this remarkable case:

"Pte. A. L. was shot through the abdomen by a rifle bullet in September 1915. He was not operated on, and he was eventually evacuated to England, where he underwent a prolonged convalescence. He eventually returned to duty in France, and he was again shot in the abdomen in June 1916. On this occasion he was admitted to hospital under the care of Captain Bell.

"At the operation very extensive and old-standing adhesions were found all over the abdomen, making complete examination of the small gut extremely difficult. At irregular intervals over several feet of small intestine, signs of previous damage were found in the shape of numerous finger-like processes, which seemed to consist of mucosa alone, and to be herniating through the gaps in the muscle coats. Between two adjacent coils there was at one point a miniature enterostomy, the lumen of which admitted a stout probe."

Although such spontaneous healing undoubtedly results, it is of academic rather than of practical interest.

Rupture of Viscera outside the Actual Course of the Projectile. —When the abdominal parietes are struck by a large shell fragment or shell nose, rupture of the hollow viscera may result though there has been no actual perforation of the abdominal wall. These cases are very similar to the injuries which one meets with in civil life as in kicks of the abdominal wall. The resulting injuries to the intestines have been explained by the theory that the viscera are caught between the unyielding posterior abdominal wall and the oncoming object.

The degree of injury varies from bruising of the intestinal wall to actual perforation.

Quite frequently one finds viscera damaged by indriven bone fragments. The liver and spleen may be injured by pieces of broken rib which have penetrated the abdominal cavity. In compound fractures of the pelvis, the caecum, the colon, or the small intestine may be damaged. Although the projectile itself does not penetrate the peritoneum, it is important to remember this possibility, because when the wound is explored it is possible that the holes caused by the bone fragments will be overlooked and the peritoneum be assumed to be intact.

A number of cases of rupture by indirect violence have been recorded. Rupture of solid organs is more common than rupture of hollow viscera. Cracks are found in the liver, spleen, or kidney, produced by shell fragments or bullets which did not actually touch the organ. We have had two personal experiences of the rupture of hollow viscera by indirect violence. In one instance there was a side-to-side wound through the thickness of the abdominal wall in the hypogastrium without perforation of the peritoneal cavity, and yet there was a tear of the posterior surface of the bladder. The second case was one of a shell wound of the right iliac fossa: the peritoneal cavity was not opened into, but the caecum was bruised and there was a perforation at the mesenteric border of the ileum.

Various theories have been brought forward to explain these curious injuries; two of them give very likely explanations: (1) It may be that when such an object as the abdomen and its contents, made up of layers of varying thickness, is hit, more friable layers underneath give way, while the more resisting overlying layers remain intact. (2) The second may be termed the "Paper Bag" theory, the intestine being ruptured by a smart blow in much the same way as an inflated paper bag is burst on being hit.

It should be remembered that there is always the possibility that a man may fall or strike some object after he is hit, and that the injury to the viscera may be due to the direct violence of the blow and not to the indirect violence of the missile.

Wound Production after Penetration.—The extent of damage to solid viscera varies from clean perforation with small entrance and exit wounds to severe laceration and destruction of the organ. Hollow viscera show a similar variety—there may be multiple small perforations of the small intestine, the gut may be torn entirely across, or a portion of the circumference of the wall may be destroyed.

The question as to how these different kinds of injuries have been caused has never been definitely answered. It is certain that a bullet, after striking the abdominal wall, is so deflected that it passes through the abdomen in a side position; when this occurs very extensive injury will result.

General Wallace believes that the different types of wounds of the small intestine depend upon the varying states of distension of the gut. As is recognised, one meets with lengths of the small intestine alternately distended with air and collapsed. If a bullet strikes a distended portion it will perforate it or cut a hole in it. If it strikes a portion which is collapsed, the intestine is so small that the bullet is

large enough in diameter to divide the whole breadth of the bowel.

The Extravasation of Contents after Injury to Hollow Viscera.—The escape of contents from the stomach depends upon the size and position of the wound and on the amount of food which is present in the stomach—large wounds of the greater curvature are necessarily associated with the greatest amount of extravasation. It is only in connection with the stomach that free gas has been seen to escape from the wound or to be present in the abdominal cavity.

The small intestine is usually empty, and it is the exception to find any degree of extravasation of contents into the peritoneal cavity. Should it happen that the intestine is loaded at the time of the wound, there is a large escape of contents; there is therefore no question of a post-traumatic paralysis being responsible for the absence of extravasation.

The large intestine is usually loaded, and presents a great contrast to the small intestine in this respect. This fact, no doubt, is due to the sedentary life of the trenches. After a wound of the large intestine, extravasation invariably occurs, but the constipated condition which is so constant tends to limit the escape.

The Comparative Frequency of Wounds of the Different Viscera.—The following table given by General Wallace in his Lettsomian lecture affords some idea of the relative frequency with which different organs in the abdomen are wounded.

The total number of cases under consideration was 965.

Viscus.	No. of Wounds.	Viscus.	No. of Wounds.
Stomach . . .	82	Kidney . . .	74
Small Gut . .	363	Bladder . . .	45
Colon . . .	252	Ureter . . .	3
Liver . . .	163	Pancreas . . .	5
Spleen . . .	54		

A Consideration of the Diagnosis of Abdominal Wounds.—The actual diagnosis embraces two questions: (1) Has the missile perforated the peritoneal cavity? and (2) Has the wound resulted in damage to solid viscera only, or are hollow viscera also involved?

These questions can often only be answered after a thorough examination is made—at other times the diagnosis is only too obvious. The various details which aid one in making a diagnosis are as follows:

(A) *The Wounded Man's Statement.*—Importance should be attached to the testimony that when the wound was received there was severe abdominal pain.

It does not constantly occur with perforating wounds, but if it should occur it is extremely suggestive. If a man is wounded in the thigh or buttock, and states that as soon as he was wounded abdominal pain was felt, it is likely that the peritoneal cavity has been perforated. There is one caution to be given, and it is this, that in wounds of the lower chest there is immediate pain which is referred to the upper abdomen.

(B) *The Clinical History following on the Wound.*—Usually a man hit in the abdomen looks ill. He is shocked and cold, and this often in spite of attempts to restore warmth. Sometimes he is apathetic and quiet, sometimes restless from pain or from distress. He may be blanched, but often the facial expression and colour is fallaciously good.

The pulse rate is usually increased, but a slow pulse does not necessarily mean that the peritoneal cavity is uninjured. A rapid pulse is caused by loss of blood, and later on by peritonitis and sepsis.

One often finds that there has been some vomiting immediately after the wound was received. If the stomach is injured it continues, but in wounds of the other viscera it ceases for an interval, to reappear later when peritonitis has developed.

Beyond blanching and a rapid pulse, there are not the

classical signs which one has been taught to associate with haemorrhage. To produce such changes as restlessness, blindness, and air hunger, the loss of blood must be very great.

Pain is nearly always present, and it varies from an uncontrollable agony to sensations little more than discomfort. There is no relationship between the amount of pain and the amount of injury.

(C) *The Examination of the Abdomen.*—The position of the wound may give all the information that is necessary in making a diagnosis. Antero-posterior wounds are easy to judge except at the lateral extreme. Here it is well to bear in mind the thickness of the flank muscles.

Lateral and oblique wounds are more difficult to judge. Below the transpyloric plane an oblique wound with its entrance on one side of the mid-line and an exit anterior to the lateral body line of the same side is very often non-penetrating. Above the transpyloric plane such a wound, owing to the rounded form of the thorax, is almost certain to be penetrating. A bullet which passes in and out between the semilunar lines probably does not open the abdomen, while the one which passes in and out outside these lines probably does. In entrance wounds at the back without an exit wound one often has to rely on symptoms in deciding whether the wound is perforating or not; the same applies to wounds of the buttocks and thighs.

Rigidity of the abdominal walls is a constant feature of abdominal wounds. It can be appreciated by the fixation of the abdomen on respiration, and by the "boarding" of the abdominal muscles when palpation is carried out. It is the most helpful feature we possess in making a positive diagnosis. In appreciating the value of the sign there are certain qualifications one must bear in mind: (1) It occurs in wounds of the lower chest; (2) it occurs in wounds and contusions of the abdominal wall without penetration of the peritoneal

cavity; (3) there may be a complete absence of rigidity with obvious penetration of the abdomen. Such cases are invariably fatal. Remembering these qualifications, rigidity is probably the most important feature of a perforating wound. If the case is seen sufficiently early the rigidity is local, later it becomes general. Morphia, if given in moderate doses, has practically no effect upon it.

Tenderness is another very valuable feature, especially when accompanied by rigidity. At first it too is local, later it becomes general.

The demonstration of free fluid in the abdominal cavity means the presence of blood, and it may be of value as a confirmatory sign. Diminution of liver dulness may be looked for, but the absence of the sign is of no significance as free gas in the abdominal cavity is only met with in certain wounds of the stomach.

(D) *X-ray Examination.*—In those difficult cases where there is a single entrance wound with doubtful abdominal symptoms, an X-ray examination is invaluable. Not only may it make the diagnosis clear, but it is of the greatest value in determining the best type of incision.

Differential Diagnosis.—There are one or two conditions which may closely simulate abdominal perforation. One has to be on one's guard not to be misled by the slightly rigid and tumid abdomen which is met with in cases of spinal injury, and especially when such injuries are accompanied by vomiting. The difficulty is sometimes increased by the presence of a distended bladder. A distinction is made by the position of the wound, by the absence of true rigidity, and by the X-ray examination. Another type of case with which confusion may arise is the penetrating wound of the lower chest, but it has neither the tenderness nor the rigidity which the abdominal case displays.

The Prognosis of Abdominal Wounds.—*The Causes of*

Death.—In those cases which die within a few hours after the receipt of the injury, death has been due in the majority of instances to haemorrhage.

A smaller proportion apparently succumb to pure shock. In the later stages general peritonitis is the most common cause of a fatal issue. There are certain wounds of the colon which die with extraordinary rapidity—they are associated with an infection of the retroperitoneal tissues, and the actual cause of death is a septicaemia; the bacillus perfringens is commonly believed to be the causal organism.

The Comparative Mortality. — While we are essentially interested in the mortality as it is illustrated in the Casualty Clearing Station, it is important to have some idea of the proportion of abdominal wounds which succumb to these injuries before reaching the Clearing Station. This is a difficult estimate to arrive at, but from inquiries we have made, we believe that about 5 per cent is an approximately correct figure.

An idea of the mortality in the Clearing Station is more easy to arrive at. It may be divided into two groups. The total mortality of all abdominal cases admitted: this figure of necessity includes a certain number of cases admitted in a too serious condition to permit of operation, while it also includes a small proportion of cases of wounds of solid organs in which no operation was necessary. The second group may be termed the "operative mortality"—embracing an analysis of all the cases submitted to operation.

Now it is well to remember that there are certain uncontrollable factors which may profoundly affect both these groups of figures. The first is the distance of the Clearing Station from the firing-line. Presently, we shall discuss this influence of time on the prognosis, but, as is to be expected, it briefly means that the longer the patient is in receiving surgical attention, the greater will be the operative mortality. We

would qualify this statement by drawing attention to the fact that an Advanced Station close to the line will receive a certain number of severely wounded men who would have succumbed before reaching a more distant centre, and this will increase the total mortality of the Advanced Station, and possibly also its operative mortality.

The second factor is the condition of the fighting. During quiet periods, when there is no great stress of work, the results are better than those obtained during a period when there are heavy casualties. The reasons for this are obvious.

Remembering these qualifications, it may be taken that the total mortality averages about 60 per cent, while the operative mortality amounts to about 50 per cent.

The following table, compiled by General Wallace, shows the results of the operative treatment up to September 30, 1917:

To show Results in Successive Periods

	July 1, 1915, to Dec. 31, 1915.	July 1, 1915, to Dec. 31, 1916.	July 1, 1915, to Sept. 30, 1917.	Jan. 1, 1917, to Sept. 30, 1917.
Total Cases	511	1288	2127	839
Moribund cases	145	250	420	170
Total mortality, excluding moribund	45·8	50·06	50·02	49
Total mortality, including moribund	61·25	60·2	59·9	59·5
Considered with view to operation	366	1038	1707	669
Operation not thought necessary	56	73	102	29
Total operations	310	965	1605	640
Total operative mortality	53·9	53·9	52·9	51·3
Hollow viscera	64·5	64·7	...	...
Stomach[1]	43·75	52·7	...	...
Small gut[1]	63·8	65·9	...	...
Colon[1]	60	58·7	...	...

[1] Uncomplicated by any other lesion of the alimentary tract.

Factors which influence the Prognosis of Abdominal Wounds.—There are a number of points which must be taken into consideration in arriving at a conclusion regarding the prognosis. These may be considered seriatim.

1. *Time.*—The majority of cases receive operative attention at some period between six and ten hours after the receipt of the injury. We have already said that up to six hours the chances are in favour of the patient; after this period they are always against him. In rare instances recovery has followed after the lapse of a long period between the receipt of the wound and the operation. So far, the limit in successful cases has been thirty-six hours for a resection of the small intestine, for a suture of the colon, and for a suture of the stomach.

The following table from General Wallace's Lettsomian lecture illustrates very well the effect of time on mortality:

591 Cases showing the Effect of Time on Mortality

	Hours.											
	2	4	6	8	10	12	14	16	18	20	22	24 and over.
To Base .	3	30	75	55	34	19	7	4	11	4	...	27
Died . .	2	30	53	59	41	23	10	12	15	11	4	52
Total .	5	60	128	114	75	42	17	16	26	15	4	79

2. *Type of Projectile.*—Of all the different missiles which cause abdominal wounds, fragments of bombs and grenades result in the smallest mortality. It might be expected that bullet wounds would show a lower mortality than shell wounds, but this is not borne out by an examination of the figures. As a matter of fact, there is very little difference between the respective mortalities of these two groups of missiles.

We quote a table illustrating these points, again borrowed from General Wallace's paper:

RELATIVE MORTALITY OF DIFFERENT PROJECTILES IN 629 CASES

	Bullet.	Shell Fragment.	Shrapnel.	Bomb and Grenade.
To Base . .	91	105	15	60
Died . . .	106	154	40	58
Total . .	197	259	55	118

3. *The Variety of Injury.*—It may seem paradoxical to say that wounds of the small intestine afford both the lowest and the highest mortality figures, yet it is true.

Uncomplicated wounds of the small intestine which are adaptable to suture show a lower mortality than any other variety of abdominal wound. When we say "uncomplicated," we mean that there is no injury to mesentery or to any other viscus.

On the other hand, complicated wounds of small intestine with extensive injury to the mesentery and to other viscera result in the highest mortality figures.

Uncomplicated wounds of the solid viscera constitute the next most promising type. Wounds of the liver are less serious than wounds of the kidney or spleen. Colon wounds are especially dangerous when the retroperitoneal tissues are injured, owing to the liability of retroperitoneal sepsis developing.

Intraperitoneal wounds of the rectum are associated with a high mortality.

As is to be expected, the highest mortality figures are associated with complicated wounds involving different viscera. Wounds of bladder and small intestine are especially fatal.

4. *The Position of the Wound.*—The bearing of this factor has been already alluded to. The points may be summarised

as follows: Wounds above the transpyloric plane are among the least serious of all abdominal perforations.

Side-to-side wounds in this situation are serious, however, especially if they are far back.

Wounds which lie between the transpyloric and intertubercular planes and, more especially, wounds which lie below the level of the umbilicus are very fatal. The reason for this is that the lower the wound, the greater is the likelihood of extensive damage to the small intestine.

Wounds below the intertubercular plane, including wounds through the hips, buttocks, and thighs, are all very serious.

Vertical wounds, many of them complicated by penetration of the chest, are exceedingly grave.

5. *The Pulse Rate.*—By many surgeons the pulse rate is considered to be one of the most valuable guides we possess in arriving at a prognosis and in doubtful cases in deciding whether operation is indicated or not. The sign is of greatest value in the higher rates. A pulse of 100 is very common, and, on the whole, promises a good prognosis. With a pulse of 120 the mortality has considerably increased. When the pulse rate exceeds 120 there are comparatively few who recover.

The following table illustrates these points; it is derived from the same source as the two previous ones:

To show the Effect of Pulse on Prognosis

	Pulse up to and including								
	60	70	80	90	100	110	120	130	140 and over.
To Base . .	1	7	23	30	108	27	37	7	9
Died . .	1	2	13	18	39	38	88	37	92
Total . .	2	9	36	48	147	65	125	44	101

General Lines of Treatment.—*Pre-operative Treatment.*—When a case of abdominal wound arrives at the operating hospital, the first question to be decided is—Is the case suitable for operation or not? There are a certain number of cases in which operation is inadvisable, and it is important to enumerate them.

1. *Cases in very Bad Condition.*—There are obviously many cases in too precarious a condition to permit of any interference, but there are a number which lie on the border-line in which it may be exceedingly difficult to come to a decision.

2. *Cases shot in the Liver Area.*—Such cases do very well on the whole if left alone, as long as there are no symptoms of haemorrhage.

3. *High Abdomino-thoracic Wounds on the Left Side.*—The type of wound especially referred to is that which enters somewhere near the mid line behind and emerges somewhere towards the posterior part of the axilla about the level of the sixth to the eighth rib. These wounds are sometimes accompanied by signs of stomach involvement, but many of them do well if left alone, and, moreover, the stomach wound is probably in such an inaccessible position that operative interference is extremely difficult.

4. *Late Cases.*—It is generally believed that twenty-four hours is the limit within which a primary operation is likely to prove successful. After this period, operation is only liable to spread infection.

Having decided that the case is one likely to benefit by operation, the next question comes to be—Is the operation to be done immediately, or is it advisable to wait for one hour or so until the patient has been somewhat restored? Fully recognising the risk there may be from increased haemorrhage, we believe that there are advantages to be gained by waiting for this short period.

During the delay the patient's condition is restored as much

as possible. Warmth—and this is a most important point—is supplied by means of a radiant electric bath, or if no current is available, by means of hot bottles or hot air. Fluid can be introduced by the bowel, subcutaneously or intravenously; the intravenous method is the best and surest. We have obtained good results by the intravenous infusion of fifteen to twenty ounces of 4 per cent gum acacia solution (Bayliss; see chapter on Transfusions, p. 269). If clinically one suspects the presence of an acidosis (air hunger, etc.), we have introduced twenty ounces of sodium bicarbonate solution either before or after the introduction of the gum solution. It is most important that arrangements be made to proceed with operation immediately after the introduction of these fluids. Transfusion results in a raising of blood pressure with an onset of fresh and severe bleeding. There is no disadvantage in giving reasonably small amounts of fluid by mouth.

The Operation. — *The Incision.* — The incision should be planned with a view to dealing with the probable nature of the injury. With in-and-out wounds where the exact course of the projectile can be mapped out it is generally easy to decide which is the best incision, but in cases with a single entrance wound it may be impossible to recognise the track of the projectile by superficial examination. It is in these cases that an X-ray is of such inestimable benefit, as it enables one to plan the incision in the best possible situation.

A paramedian incision is the standard method of opening the abdomen, and it is always well to employ a long incision, certainly not less than six to eight inches.

In those cases where the missile has perforated the body from near the mid line to the loin, as shown either by the position of the wounds or by a skiagram, a transverse incision either horizontal or parallel to the upper or lower abdominal limits gives excellent access. It affords the easiest route for examination of the colon and its flexures, for the kidney, or

the spleen. It further permits of examination of the small intestine.

Technique when the Abdomen has been opened.—If the abdominal cavity contains a large quantity of blood, enough of this is rapidly swabbed away with a long roll of dry gauze to clear the view. A systematic examination of the various viscera is now carried out. We begin by picking up the caecum and recognising the ileo-caecal junction; we work back rapidly along the whole length of small intestine, examining not only the gut but also its mesentery. The large intestine is reviewed, special attention being paid to the various flexures. If necessity arises, the stomach on both aspects, the duodenum, the liver, and spleen are examined. It is a wise precaution to palpate both kidneys, especially the left kidney, in cases of damage to the spleen. The pancreas is reviewed during the examination of the posterior wall of the stomach. The pelvic viscera are examined last, and to facilitate their examination the residual haemorrhage is more completely cleared away.

Where areas of obvious soiling and sepsis are present, we mop away the infecting material, afterwards swabbing the part with warm eusol. We have entirely given up systematic washing out of the peritoneal cavity.

Drainage is called for less often than one would expect. We entirely close up all wounds of solid viscera and the majority of cases of wounds of the stomach and small intestine, exception, of course, being made where there is very obvious soiling.

In wounds of the colon, however, the question of drainage is on an entirely different footing; these wounds cannot be drained too thoroughly, more especially the fixed portions of the colon, the ascending and the descending; the drainage should be established as much as possible in the loin. Unless it is already infected, great care should be taken to avoid opening and so infecting the retrocolic tissues.

When the seriousness of the patient's condition demands great celerity, we close the abdominal wall with through-and-through sutures of silkworm gut, guarded where they pass over the wound junction with small pieces of capillary rubber tubing; in the insertion of these we employ a Doyen's handled needle.

Throughout the operation speed is an important factor, coupled with every possible avoidance of shock.

Post-operative Treatment.—This is very similar to that which is adopted after any severe abdominal operation in ordinary surgical practice. Special attention is paid to the administration of fluids by the usual means; blood transfusion may be employed.

These patients are generally nursed in a semi-recumbent position. As to the administration of morphia, it is better to give it than to withhold it if the patient is restless or in pain.

As regards the securing of bowel action, our routine has been to give an intramuscular injection of pituitrin (1 c.c.) on the fourth day, and if there is no result in twenty minutes, a glycerine enema is administered.

Post-operative Complications.—We have noticed that acute dilatation of the stomach is an occasional complication in the post-operative history. It occurs subsequent to intraperitoneal wounds, and also secondary to retroperitoneal wounds and infection. About forty-eight hours after the operation the patient complains of epigastric distension and a feeling of sickness, frequent mouthfuls of stomach contents are evacuated, and later, large quantities of foul fluid containing bile and retained pancreatic juice are vomited. The signs and symptoms somewhat suggest a general septic peritonitis, but the distension and discomfort are at first, at any rate, localised to the epigastric region.

In its early stages the complication is easily arrested by

stomach lavage. The process may have to be repeated several times before relief is complete.

The other common post-operative complication is the development of a peritonitis.

Mention must be made of our experience of Sampson Handley's operation for this complication. Sampson Handley originally recommended the operation in cases suffering from pelvic peritonitis secondary to appendicitis and producing a condition which he called "ileus duplex," the obstruction being in the lower ileum and the pelvic colon. The operation consists in anastomosis of the lower ileum to the pelvic colon, or, under certain conditions, of the lower jejunum to the transverse colon, a caecostomy being done in each instance. After certain cases of wounds of the intestine, a slowly developing peritonitis appears; it is most marked in the pelvis, and pathologically it produces a condition of ileus very similar to that which Sampson Handley describes. In four cases we have performed the suggested operation, in three cases anastomosing the lower ileum to the pelvic colon, and in one instance the lower jejunum to the transverse colon.

In one case the peritonitis was so intense and so general that the patient succumbed on the following day. In the other three cases the patients survived for five to seven days after the operation. For about three days there was an improvement, the bowels moving and sickness being arrested, but from this point the peritonitis appeared to re-establish itself and to progress with results eventually fatal. The operation was of temporary benefit, but it did not arrest the eventual development of the inflammation.

Wounds of Individual Organs.

Oesophagus.—Wounds of the oesophagus are very rarely met with. They undoubtedly occur, but on account of the

proximity of the tube to the spine and the great vessels and the associated wounds of these parts the condition is generally rapidly fatal.

Stomach.—*Morbid Anatomy.*—Wounds of the stomach are often associated with wounds of the hollow viscera, the jejunum and colon, and of the solid viscera.

All types of wounds are found, from the small perforations caused by a rifle bullet passing in an antero-posterior direction

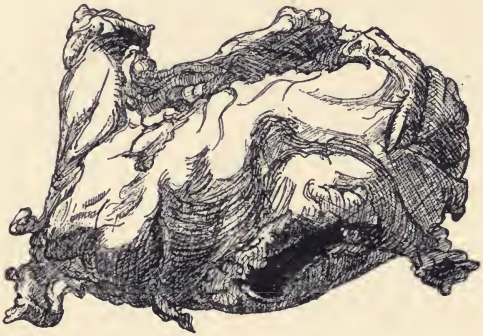


FIG. 34.—Bullet wound of the greater curvature of the stomach. Note the slit-like character of the wound owing to projectile having passed parallel to the long axis of the stomach.

to the enormous lacerations produced by large fragments of shell. When the line of the flight of the projectile is more or less parallel to the walls of the stomach, the wound becomes larger, sometimes a long slit, sometimes a slit followed by a perforation, and more rarely two perforations on the same surface.

When the greater or lesser curvatures are injured by projectiles passing in an antero-posterior direction, there result extensive V-shaped injuries involving both walls.

When the wounds are small, there is no pouting of the mucous membrane, but in the case of linear wounds there is considerable protrusion.

The haemorrhage is not severe unless the wound actually involves one of the larger branches of the blood-vessels.

Clinical Features.—Wounds of the stomach demonstrate the clinical features which one associates with wounds of the hollow viscera of the abdomen generally — there is pain, collapse, rigidity of the abdominal wall, with tenderness on pressure; but, in addition to these general features, there are certain distinctive signs. Vomiting is a very constant feature, and in the vomited matter it is rarely that one fails to find the presence of blood. The degree of collapse is less marked than that found in intestinal injuries, but whether or not this is related to the smaller amount of haemorrhage one cannot say.

The degree and the variety of the clinical features are influenced considerably by the situation of the lesion. Pain would appear to be more intense when the cardiac or pyloric ends of the stomach are involved; it is correspondingly less so when the wound is related to the body of the stomach.

Wounds of the curvatures of the stomach, with the greater destruction which invariably accompanies them, are associated with severe symptoms of collapse. The clinical features are also influenced by the condition of the stomach at the time of injury; if the stomach contains a quantity of food the wound is followed by more intense clinical features than if the organ had been empty.

Treatment.—Operation is to be advised in all cases except those in which, from the track of the bullet, the wound is most probably situated near the oesophagus or in the upper portion of the cardia. The best incision is a paramedian one. If it is apparent that the cardia is wounded and conditions are otherwise suitable for operation, access to the injured part may be gained through the thorax and diaphragm (*see* section on abdomino-thoracic wounds).

After exposure an examination is made of the various

portions of the stomach; if there is any possibility of the posterior wall having been damaged, the anterior layer of the great omentum is torn through and this portion of the stomach is reviewed.

The great majority of stomach wounds are capable of suture. When the antrum or the duodenum are severely damaged, it may be necessary to perform a gastro-enterostomy. This may also be necessary when the wound, after suturing, has resulted in marked narrowing of the stomach.

Prognosis and Mortality.—It might be expected that in

FIG. 35.—Bullet wound of small intestine, showing the rosette appearance of the exit wound.

uncomplicated wounds of the stomach the mortality would be comparatively low. This expectation has been disappointed. The average mortality is about 50 per cent, and when the case is complicated with lesions of other hollow viscera the mortality reaches 75 per cent.

The common causes of death are shock, haemorrhage, and peritonitis. A later cause of death, and one less common than might be imagined, is secondary haemorrhage.

Small Intestine.—*Morbid Anatomy.*—Wounds of the intestine are complete or incomplete; that is to say, they open the lumen of the bowel or they bruise or tear its coats.

When the missile is a bullet, the most common injuries are

perforations made by striking the bowel at right angles to its long axis. There are entrance and exit wounds through which the mucous membrane pouts in rosette fashion. The eversion of the mucous membrane is due to its redundancy and to a retraction of the longitudinal coat of the bowel. Microscopical examination of the wound edges shows that the damage is purely local, and there is only a slight infiltration of blood around the edges. As the flight of the bullet comes to

FIG. 36.—Multiple bullet wounds of the small intestine; many of them show the typical appearances of the entrance and exit wounds.

lie more in the long axis of the gut the wound becomes slit-like. In other cases there are different degrees of division of the gut in its transverse axis, varying from an irregular wound of the free edge to complete division of the bowel.

When the intestine is contracted and ribbon-like at the time of injury the damage is greater than if it had been distended. Shell fragments cause wounds of all types depending upon the shape of the fragments.

Bomb wounds are generally small multiple perforations of the gut often collected over quite a small area.

It is remarkable how seldom there is a massive escape of contents from the lumen of the gut. Emptiness of the bowel

FIG. 37.—Bullet wound in long axis of the small intestine: the arrow indicates the probable course of the bullet, and the extensive destruction of the gut-wall is shown.

at the time of the wound is a more potent factor in this than any post-traumatic paralysis.

Clinical Features.—The clinical features are those of commencing peritonitis coupled with the evidences of rapid and progressive haemorrhage.

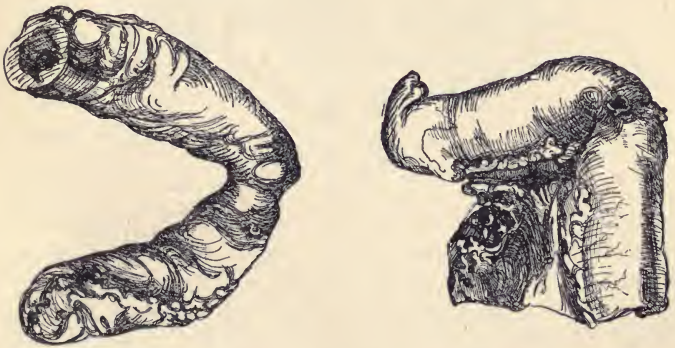


FIG. 38.—Multiple wounds of the small intestine caused by small bomb fragments.

Treatment.—A long paramedian incision is the rule.

In localising the sites of injury we have followed a well-defined routine. After opening the abdomen the caecum is identified, and from it the small intestine is traced upwards,

beginning with the lower end of the ileum. As each perforation of the gut is exposed, it is wrapped up in a small moist swab; to one side of the swab a length of tape is stitched. This is slipped through the mesentery and doubled twice round the gut covered by the swab; in this way each perforation is marked, and there is less chance of massive infection from the injured gut. The whole length of the small intestine must be examined before any decision as to treatment is arrived at. There is nothing more disconcerting than to deal with a perforation by resection and to find that a few inches farther on

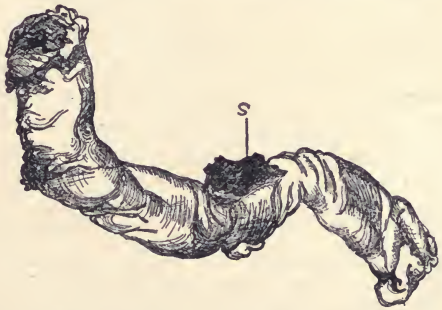


FIG. 39.—Shell wound of small intestine with shell fragment embedded in the wall of the gut.

there is another perforation which could have been included in the same procedure.

When the degree of damage to the gut has been brought under review, there are two varieties of operative treatment which may be followed. These are: (1) simple suture of the perforation; (2) resection of the damaged intestine, followed by a lateral or end-to-end anastomosis.

1. *Simple Suture of the Perforation.*—At one time it was believed that a wound to be suitable for suture should be small, without damaged edges and with an intact mesentery. Further experience has shown that the range of possible

suture is much more extensive than we had at first imagined—there are few wounds of the small intestine which do not prove amenable to suture. It may be said that there are three possible contra-indications to its use: (1) extensive damage to the mesentery; (2) a wound which, when sutured, results in marked narrowing of the gut, and the type of wound which most commonly results in this complication is one running obliquely across the long axis of the gut; (3) when the perforation is associated with resulting necrosis of

FIG. 40.—Shell wounds of small intestine showing extensive destruction of the gut.

the surrounding bowel—a condition which is more common in the colon than in the small intestine.

The method of suture has the advantage of speed (when the perforations are not too numerous), of simplicity of technique, and of lessened post-operative shock.

There are, of course, distinct disadvantages. The suture may result in considerable narrowing of the lumen of the gut, and where there are a number of similar sutures within a short distance of each other the multiple narrowing becomes a very real objection. The second disadvantage is that if the perforations are very numerous their closure would take

considerably longer than the time which would be entailed in a resection of the damaged gut.

In the suture operations which we have done we have not excised the edges of the wound, and we have used a linen thread for stitching.

We have from time to time made use of omental grafts to reinforce doubtful suture lines.

2. *Resection of the Damaged Intestine, followed by Lateral or End-to-end Anastomosis* — We originally favoured this method of treatment in preference to multiple and extensive suturing. We believed that the indications for the operation were the multiplicity of the perforations, the extent and degree of the perforations, and the involvement of the related mesentery; we now consider that only the last constitutes a real indication.

Under exceptional conditions, such as have been already stated, the first two indications may be entertained.

The advantages of resection may be summarised as follows: The operation is complete and thorough, the risk of damage following a mesenteric involvement is minimised, there is less likelihood of sloughing of devitalised intestine, and there is less possibility of subsequent stricture.

Several disadvantages may be quoted: The complexity of the technique, the time the operation takes, and the intense degree of shock which almost invariably follows it. The first and the second are no real objections, but the third is a more potent one; it is the one feature which has led us to abandon the resection operation for the multiple suture. The degree of shock is infinitely greater after a resection operation than after an extensive multiple suture operation.

Having weighed the choice of the operation, the question next arises whether the anastomosis is to be lateral or end-to-end. When we began this work, we favoured and used an end-to-end anastomosis, on the ground that it could be

accomplished in a shorter period of time than the lateral anastomosis. We discovered that this method was apt to be followed by a certain degree of paresis in the proximal segment, with subsequent distension and eventual obstruction. On several occasions we have had to perform a second short-circuiting operation to overcome the obstruction.

The gut appears to be predisposed to the distension from various causes: the general degree of nerve shock, and more especially of sympathetic nerve shock; the paresis of Auerbach's plexus as a result of the blow; the presence of blood in the peritoneal cavity, and the degree of the peritonitis which is invariably present. As a result of this disadvantage we began to employ a lateral anastomosis, and from it we had undoubtedly greater satisfaction and better results. At this point one must allude to the bearing which experimental work had upon the feature. End-to-end anastomosis of small intestines in animals was inevitably followed by distension of the gut above the suture, with subsequent death of the animal. When lateral anastomosis was performed no complications arose, and recovery was invariably the result. The technique of the end-to-end anastomosis was then modified in so far as the mucous membrane was clipped away around the cut edge of the bowel; a subsequent distension did not occur, and recovery followed the operation.

The influence of blood and peritoneal infection was submitted to experimental investigation. After resection and anastomosis of the gut, both end-to-end (modified method) and lateral, a quantity of blood was placed in the peritoneal cavity and a peritoneal infection was started by allowing a slight escape of intestinal contents; no subsequent distension occurred, a fact pointing to the conclusion that these complications have little bearing on the development of the subsequent distension.

In point of time the lateral anastomosis takes a few

moments longer, in so far as it involves closing the open ends of the gut, but it apparently largely overcomes the possibility of distension of the proximal segment.

Mortality and Prognosis.—In cases of wounds of the small intestine uncomplicated by wounds of other hollow viscera the mortality is about 65 per cent. When other hollow viscera are damaged the mortality is about 75 per cent.

Of the various causes of death after operation, peritonitis is the most common, while haemorrhage and shock show a very similar figure.

Large Intestine.—*Morbid Anatomy.*—The injuries of the large intestine are very similar to those one meets with in the small gut. There are certain differences which are to be accounted for by (1) the larger size, (2) the absence of coils, (3) the absence of mesentery in certain situations, (4) the proximity of certain portions to bone.

1. The larger size of the colon makes it more liable to tears or perforations than to complete division.

2. On account of the absence of coils, multiple injuries are not common. If they occur, they are few in number and they are met with at the bends.

3. The absence of mesentery in some situations means a liability to retroperitoneal wounds. These are difficult to find, and on account of the liability of retroperitoneal sepsis developing are associated with a large mortality.

4. The proximity to bone means that when there is a compound fracture of the related bone spicules are apt to be driven into the adjacent gut.

Clinical Features.—The clinical features are very similar to those of small intestine injury; they are, primarily at least, not so widespread.

Subsequent to the injury three possibilities may develop:

1. The effusion and infection may remain localised.

2. The infection may spread and a general peritonitis result.

3. The infection may extend into the retrocolic and retroperitoneal tissues, and the group of symptoms which we have called "colon septicaemia" may develop.

(1) In the first instance (if the effusion and infection remain localised) the patient's general condition is good, there are signs of a local inflammatory focus, and further neglect of the condition will result in abscess formation and the establishment of a faecal fistula.

(2) The second possibility is accompanied by all the signs and symptoms of a general peritonitis—the peritonitis is generally an acute and progressive one.

(3) In the third instance the features of an intensely rapid septicaemia appear. The signs may appear and develop with startling suddenness. Patients suffering from this condition have generally a grey pallid appearance, and it suggests that there has been an extensive loss of blood, but investigation of the history will show that this has not been the case. There is restlessness and great uneasiness. Signs of delirium appear and become established. The pulse is characteristic; from the normal rate it very rapidly increases, so that in the course of a few hours it may have reached a speed of 150 a minute. The respiration rate increases until it reaches 40 to 50 a minute.

The temperature behaves variously; in the most intense cases it falls to subnormal and remains so, in less acute cases it rapidly rises to a considerable height (104 to 105 degrees), and shortly before death it falls with a crisis. Vomiting is common, frequently in mouthfuls, ultimately resulting in acute dilatation of stomach. Before death the delirium passes into complete loss of consciousness, and the extreme general pallor is replaced by a slightly jaundiced appearance. The abdominal signs are primarily those of localised infection. Later the abdomen becomes markedly distended; there is not the same degree of tenderness or muscular rigidity as one associates with a generalised peritonitis.

Post mortem the signs are those of an acute septicaemia, with marked congestion of the viscera; frequently there are haemorrhages throughout the substance of the spleen. The Bacillus perfringens has been isolated from the blood and from the visceral lesions.

Treatment.—We have drawn attention to the liability of wounds of the colon to become localised, and this fact has a bearing on the operative treatment. The bearing is that, if the patient comes under treatment at a period longer than twenty-four hours after the receipt of the injury, it is a wise principle, primarily at least, to enlarge the original wound, on the possibility that the infection is becoming localised. At an earlier period than twenty-four hours it is probably better to open the abdomen through a separate incision.

We have been impressed with the risk run of overlooking injuries to the colon; the risk is greatest when the wound lies in one or other of the flexures of the gut.

The actual operative treatment may be summarised in the following methods: (1) simple suture; (2) suture with a proximal colostomy; (3) colostomy at the site of injury. The operation of resection may be left out of account; it is rarely advisable to practise it in this type of surgery.

At first we followed the practice of a proximal colostomy in combination with the operation of suture. There are the obvious advantages that it increases the safety of the suture, while it obviates the passage of faecal matter through the damaged gut. At this time we were suspicious regarding the viability of the line of colon suture, and we felt that the colostomy added greater security. Later, we recognised that the performance of proximal colostomy was rarely necessary, and we have therefore almost abandoned its use. We now reinforce the suture line by an omental graft. We believe that our results have improved since we have altered our procedure.

When the wound of the colon is very extensive, colostomy at the site of injury is the only possible procedure.

We believe that most wounds of the colon should receive very thorough local drainage. The establishment of efficient local drainage is the means of lessening the likelihood of development of infection of the retrocolic tissue and the establishment of colon septicaemia.

Prognosis and Mortality.—The mortality of colon wounds uncomplicated by other lesions of the alimentary tract is about 58 per cent. The mortality is greatly increased in those cases in which an artificial anus becomes necessary—in these cases it is as high as 73 per cent.

The Rectum.—*Morbid Anatomy.*—Wounds of the rectum may be intraperitoneal, extraperitoneal, or a combination of both. The entrance wound is generally in the buttocks. Of all possible types of wound, that most commonly met with is the wound of the anterior wall of the rectum, low down and immediately above the floor of the pouch of Douglas. The wounds are nearly always complicated by compound fracture of the pelvis or wounds of the small intestine or bladder.

There is liability to severe bleeding from the large pelvic vessels in close relation to the rectum. Unless the wound is large, it is unusual to find intestinal contents escaping to any degree.

Clinical Features.—There are all the features which one associates with injury to the abdominal viscera; in the early stages the symptoms are ill-defined and are liable to be overlooked.

Recent haemorrhage is usually found escaping from the rectum. There may be retention of urine, and if urine is voided, pain is complained of in the region of the bladder.

In uncomplicated wounds of the rectum the degree of shock is not severe.

Treatment.—It is necessary in every case to explore the

abdomen. It is possible that beyond an infiltration of blood in the pelvic tissues no wound may be found. In such a case the injury is probably extraperitoneal.

If an intraperitoneal wound is discovered, it is sutured with a primary layer of catgut and a series of linen-thread Lembert sutures. The question has then to be considered whether or not a temporary colostomy is necessary. If the wound in the rectum is severe, it is advisable to do a temporary colostomy. The problem of whether an inguinal or a transverse colostomy be performed must be decided by such points as the situation of the surface wounds and the degree of damage and position of the rectal wound.

Transverse colostomy has the advantages that it is more easily controlled, that the restoration of the continuity of the bowel is more easily accomplished when the need for the artificial opening is past, and that should surgical interference be necessary later in order to repair the damaged rectum, the pelvic colon can be mobilised and brought down to the injured part.

If it is found that the wound of the rectum is extraperitoneal, the entrance wound is opened up and efficient drainage established; in fact, in every case of wound of the rectum it is advisable to open up the entrance wound very thoroughly, as this diminishes the risk of a subsequent pelvic cellulitis. The question of whether a colostomy is necessary in an extraperitoneal wound must be decided by the character and position of the wound.

The Bladder.—*Morbid Anatomy.*—The missile may reach the bladder laterally, antero-posteriorly, or from above or below; the relationship of the wound to the peritoneum will vary according to the portion of the bladder which is injured.

Complications are exceedingly common; generally the pelvis is fractured, frequently the hollow viscera are injured—the small intestine or colon.

The missile may be arrested inside the lumen of the bladder, and this is most likely to occur when the projectile enters the full bladder. If the bladder is empty when hit there is more likelihood of there being entrance and exit wounds.

Clinical Features.—The clinical features are generally disguised by the fact that they are complicated by the signs and symptoms of other wounded viscera; occasionally there has been an opportunity of observing an uncomplicated case.

The features are those of a slowly developing peritonitis with at first local pain over the bladder and afterwards general abdominal pain. If the patient can void urine, haematuria will probably be present. Urine, however, may be discharged into the peritoneal cavity in such quantity that none is passed by the urethra.

When the wound is extraperitoneal, dulness appears above the pubis and there is tenderness and rigidity over the lower abdomen. The infiltration spreads in the pelvis and escapes by the sciatic notch into the buttock, by the obturator foramen into the upper part of the thigh, or along the inguinal canal into the scrotum.

The use of the cystoscope is not of diagnostic value as distension of the viscus cannot be obtained.

Subjectively there is pain, tenesmus, and frequent desire to pass water with inability to do so; often a few drops of blood are passed after much straining. Rectal spasm may also be present. Urine mixed with blood may escape from the wound.

Treatment.—In the intraperitoneal variety the abdomen is opened and explored, the tear in the bladder wall sutured and drainage of the pelvis established. We afterwards tie in a urethral catheter in order to prevent over-distension of the viscera, and so avoid strain upon the sutures.

When the rupture is extraperitoneal a suprapubic incision is made down to the bladder and the anterior wall examined. If the rupture is easily accessible the wound is sutured and

a drain inserted down to the bladder. If the rupture is inaccessible, the bladder is drained suprapubically, and if necessary a counter-drain is inserted in the perineum.

Colonel Fullerton does not think that a suprapubic cystotomy is necessary in extraperitoneal wounds, as he has often seen cases at the Base do well, discharging urine through the various fistulous tracks caused by the projectile's entrance through the buttock or thighs. He states that urine is an aseptic fluid, and therefore need not be feared. It is true that many such wounds reach the Base, but at the Front one sees cases with extraperitoneal bladder wounds do badly and show signs of septic intoxication, and after meeting with such instances, one does not feel inclined to hold one's hand on the chance of the case running a favourable course.

When the rectal surface of the bladder is wounded it is best, as Major Hamilton Drummond suggests, to open the bladder and suture the wound from the inside.

Prognosis and Mortality.—In uncomplicated bladder wounds the mortality is about 56 per cent. Death is usually due to shock or haemorrhage, and when compound fracture of the pelvis is present, as it so commonly is, the liability to both of these is greatly increased.

The Liver, Gall-Bladder, and Ducts.—*Morbid Anatomy.*—Wounds of the liver are of all types, from a simple perforation, or avulsion of an edge, to an almost complete disruption. The wounds are generally compatible with the size of the missile. The friable nature of the liver substance especially lends itself to tearing and fragmentation—from a central perforation radiating fissures pass in all directions, or a whole lobe may be shattered and destroyed.

The track of the projectile is at first ragged and bloody—after a period of from twelve to twenty-four hours it becomes of a dirty yellow colour owing to a staining by bile.

Microscopical examination shows that the injury is limited

to the vicinity of the wound: if destruction is found at some distance from the wound, it is probably the result of an infarction phenomenon (Dunn).

The haemorrhage depends upon the size of the wound and the calibre of the vessels which have been wounded: bleeding generally ceases spontaneously in from six to ten hours.

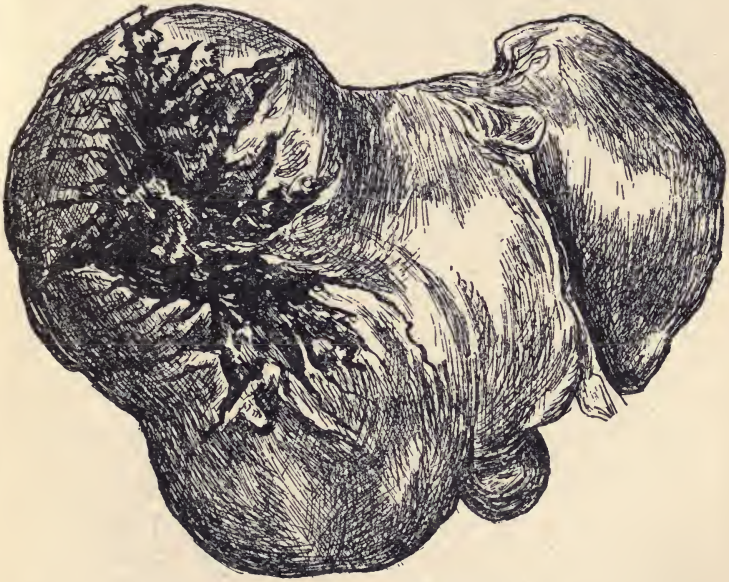


FIG. 41.—Shell wound of liver, showing the fissuring character of the lesion.

The gall-bladder and the common and cystic ducts have been wounded. The close relationship of the right pleura and lung to the right lobe of the liver is responsible for the fact that a wound of the liver is very frequently accompanied by damage to the overlying pleura or lung.

Clinical Features.—The clinical features may be remarkably scanty. If the wound has involved the lung and pleura, the

pulmonary signs frequently disguise the abdominal features. Generally pain is complained of over the liver and beneath the right scapula. The pulse, temperature, and more especially the respiration, are increased. There is usually some rigidity of the upper part of the abdominal wall; we have observed that the rigidity is increased and becomes more generalised when there is a considerable effusion of blood into the peritoneal cavity. By percussion an effusion can sometimes be demonstrated in the right iliac fossa. One would expect greater interference with the excretory function of the liver than is actually the case. On only one occasion have we seen a large effusion of bile into the peritoneal cavity. Post-traumatic jaundice is exceptional, and when it occurs it generally indicates a septic change secondary to the wound. There is no alteration in the bile content of the faeces, and the urine is free from bile.

Treatment.—Many cases require no operation, the liver is obviously the only organ wounded, and the patient's general condition is good.

Operation is called for when there is a possibility of hollow viscera being wounded, or when there is a progressive haemorrhage.

The suitable incision for obvious liver wounds is either an *f*-shaped rectus incision or a subcostal one. Recently the French have recommended an incision parallel to the costal margin passing through the costal cartilages. Access to the upper surface of the liver is said to be greatly facilitated by this method. In many liver wounds good access is obtained by the trans-pleural route. The actual treatment of the liver wound consists in packing it, suturing it, or leaving it alone.

Prognosis and Mortality.—The mortality of uncomplicated liver wounds is about 30 per cent. The mortality has a distinct relation to the size of the wound on account of the

quantity of blood lost and the amount of damage to the liver substance.

Death generally results from shock and haemorrhage.

Pancreas.—Very few wounds of this organ have been noted. General Wallace found only 5 cases in a total of 965 operations for abdominal wounds. Possibly many such injuries are missed and diagnosed as retroperitoneal haematoma. In many cases the wound is associated with injuries to other organs, and more especially to the stomach, the liver, and the kidney.

There are no distinctive symptoms, but at operation fat necrosis of the omentum is generally noted.

As regards treatment, we append the notes of one case in which the wound was successfully treated.

There was a bomb wound of the left loin. The abdomen showed all the signs of injury to the abdominal viscera, the signs being most marked in the upper abdomen; there was persistent sickness.

The abdomen was opened in the middle line; there was some free blood in the peritoneal cavity. Examining the stomach, the gastro-hepatic omentum was found to be perforated and the lesser curvature of the stomach torn; the coronary artery was divided and bleeding. The posterior wall of the stomach was exposed but no perforation was found. There was a quantity of free blood in the lesser sac of the peritoneum. On examining the pancreas it was found to be perforated through and through, immediately to one side of the aorta; the projectile was finally found embedded in the left lobe of the liver.

A rubber tube was sutured to the anterior wall of the pancreas and brought to the surface above the stomach through the gastro-hepatic omentum. No complications developed and the patient made a good recovery.

Prognosis and Mortality.—These cases are often primarily

fatal on account of the proximity of the aorta and vena cava.

In those cases which come to operation the mortality is high, but the figures available are too few to give any representative statistics.

The Spleen.—*Morbid Anatomy.*—Wounds of the body of the spleen often pass through the organ without producing

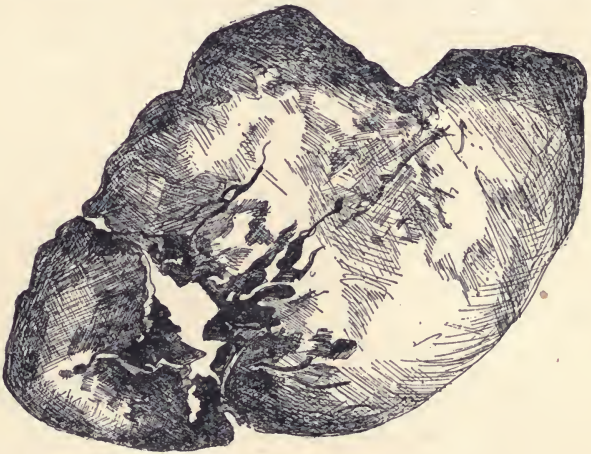


FIG. 42.—Bullet wound of spleen.

extensive damage: there is a small central perforation with radiating fissures.

When either pole of the spleen is wounded the damage is more extensive, and sometimes one or other pole is entirely torn away.

In one instance we have met with a curious type of injury to the spleen. The man was wounded by a rifle bullet in the lowest rib at the posterior axillary line. Upon opening the abdomen the cavity was found to be full of blood, the spleen was disorganised into a mass of bleeding pulp, the lower ribs

were fractured and their sharp ends had been driven into the spleen, and the repeated movement of respiration had continued the damage thus begun. The damage was so extensive that splenectomy was necessary.

When the wound involves the hilum the bleeding is intense; in other situations it has a tendency to cease spontaneously, and it is very readily controlled.

Wounds of the spleen are nearly always complicated by

FIG. 43.—Tangential bullet wound of spleen. In this case the injury to the spleen was accentuated by indriven fragments of rib.

wounds of one or more of the neighbouring viscera—the left kidney, the left pleural cavity, and the splenic flexure of the colon. It is interesting to note that wounds of the spleen and the stomach are very rarely associated.

Clinical Features.—The symptoms are mainly those of haemorrhage, and the diagnosis is made on these and on the position of the wound.

Treatment.—The treatment of wounds of the spleen varies according to the degree of damage sustained. A small penetrating wound unassociated with much bleeding is better

left uninterfered with. Wounds accompanied by extensive destruction of the organ, or complicated by severe bleeding—for example, wounds of the hilum—are best treated by removal of the organ. The middle group of cases are those with a limited wound of the region associated with moderate bleeding; the local treatment of these consists in arrest of the haemorrhage and, if possible, closure of the wound in the spleen; these *desiderata* can be attained by the use of sutures and packing.

In gaining access to the spleen we have generally used an incision parallel to the costal margin.

Prognosis and Mortality.—The mortality in uncomplicated cases is about 50 per cent. Shock and haemorrhage are the main causes of death.

The Kidney and Ureter.—*Morbid Anatomy.*—A certain proportion of kidney wounds are slight, more especially those in which the edges or poles are affected. When the centre of the body of the kidney is injured, the damage is severe and the kidney may be found to be ruptured into several portions. But the apparent triviality of the kidney wound is sometimes no guide to the organic disintegration which occurs; even in the slightest wounds the organ often shows extensive microscopical changes of minute necrosis and haemorrhage.

The bleeding is not as a rule excessive, unless some of the larger vessels have been divided; as a rule it ceases spontaneously.

Generally blood is present in the urine; occasionally the pelvis of the kidney and the upper end of the ureter become blocked by blood-clot, and this sign is then in abeyance.

Haemorrhage from the kidney extends widely over the retroperitoneal tissues, and if an infection develops in this region the result may very easily be fatal.

In two instances we have found both kidneys hit by the same missile—side to side wounds. In one of the cases there was a paraplegia. Both cases were fatal.

Clinical Features.—The first indication that the kidney has been damaged is generally got from the position of the wound. One would reasonably expect haematuria to occur, but, as we have pointed out, under certain conditions this sign may be absent. When the wound is uncomplicated, involving the kidney alone, the physical signs are those of a retroperitoneal injury; the general condition is good, the pulse rate being only slightly increased. The local signs are those of partial fixation and rigidity of the abdominal wall, tenderness on palpation usually confined to one-half of the abdomen, and occasionally the presence of fluid, demonstrated by percussion in one or other flank.

A secondary haemorrhage is a fairly frequent late complication; it occurs most frequently during the second or third week after injury.

Treatment.—Generally speaking, there are three possible operative procedures which one may be called upon to perform: (1) simple drainage; (2) suturing the kidney; (3) nephrectomy.

Simple drainage will be the operation of choice in the majority of cases; in many cases in which formerly we would have removed the damaged organ we now rely upon efficient drainage, leaving a nephrectomy, if necessary, until a later date. To expose the viscus we employ a vertical posterior incision. Suture of the damaged kidney we have only employed in one instance—the viscus was almost severed into two halves by a horizontal tear on its posterior surface; with a view to saving the organ, and as the bleeding was not severe, the two halves were stitched with interrupted catgut sutures. The result was unsatisfactory, for sepsis developed with disastrous results.

The indications for nephrectomy are extreme laceration of the kidney, and haemorrhage from the larger renal vessels. As it is very often necessary to examine the abdominal viscera in addition to dealing with the kidney, we originally removed the kidney through an anterior incision. We believe that

this operation is associated with very considerable shock, and that it is advisable first to explore the abdomen anteriorly, afterwards removing the damaged kidney through a lumbar incision.

Prognosis and Mortality.—In uncomplicated wounds the mortality is low—about 17·5 per cent. When death occurs, it is the result in early cases of shock and haemorrhage, and in late cases of sepsis.

Ureter.—The ureter is not frequently injured. The injury is generally discovered in the course of an exploratory laparotomy, and suture and drainage are the methods of treatment.

Wounds of Duodenum.—Wounds of the duodenum have a very high mortality, and the majority of the cases die before surgical assistance can be obtained. This is explained by the proximity of the duodenum to such structures as the aorta, vena cava, and portal vein, wounds of which would necessarily be rapidly fatal.

In the majority of the cases we have seen the second part of the duodenum has been wounded—more exactly at the junction of first and second portions; in one instance the third part of the duodenum was injured. The thin-walled duodenum is very readily torn, and the wound is larger than is usual in small intestine. Haemorrhage is not generally severe; there is an escape of bile into the peritoneal cavity and occasionally of food; there is usually an associated wound of the right kidney. In several instances we have found multiple fat necrosis.

Clinical Features.—The clinical features are similar to those of wounds of small intestine; there is generally intense shock, and sickness is usually present.

Treatment.—Operative treatment consists in suture of the torn bowel; the possibility of performing at the same time a gastro-enterostomy must be considered. Suture of the

duodenum may result in contraction and narrowing, and further, duodenal wounds are especially liable to leak after suture; both of these possible disadvantages are avoided by the performance of a gastro-enterostomy.

Suture of the duodenum is facilitated when the intestine is mobilised in the manner suggested by Kocher, by incision of the parietal peritoneum on the outer side over the right kidney.

CHAPTER VIII

CHEST WOUNDS

THERE is probably no branch of War Surgery which has undergone a greater revolution since the beginning of the campaign than that of wounds of the chest.

At the beginning of the war we were interested merely in the question of diagnosis of a haemothorax and whether or not aspiration of the blood was indicated. Aspiration became a routine procedure, and simple aspiration was followed by replacement of the aspirated fluid by oxygen in order to diminish the disagreeable symptoms sometimes produced by the removal of a large quantity of blood from the pleural cavity. These procedures yielded excellent results where simple haemothorax was concerned, but it left untouched the urgent problems of an open chest wound—a septic foreign body in the lung or pleural cavity and an infected haemothorax. It is in dealing with these problems that the great advances of the past year have been made. Immense credit is due to the pioneer work which has been done by M. le Médecin-Majeur Duval of the French Medical Service, and by Colonel Gask, D.S.O., R.A.M.C.

The Classification of Chest Wounds.—The most useful working classification is based upon the condition of the wound of the parietes, and on this understanding chest wounds may be classified as follows:

A. Closed entrance and exit wounds, no foreign body retained.

B. Open wounds with entrance and exit wounds or with entrance wounds and a retained foreign body.

C. Open tangential wounds at the periphery of the chest circumference.

When first admitted, all cases may be grouped into one or other of these three classes. Class A, on further investigation, is subdivided into two groups according to whether the haemothorax is infected or not. Such a working classification is essential. Groups B and C demand the earliest possible operative interference. Group A, if uninfected, will do well without any more active treatment than occasional aspiration; if infected, later operation will be necessary.

Pathological Anatomy.—The injuries inflicted by a projectile entering the chest may be considered in effects upon (1) the chest wall, (2) the injured lung, (3) the opposite lung and mediastinum.

(1) *The Chest Wall.*—The damage done to the chest wall may take a great variety of forms.

There may be a clean antero-posterior perforation of the thorax, the missile, in this case generally a rifle bullet, cleaving its way through all the tissues with which it meets, but without coming into contact with the bony framework of the chest. In many cases, however, and in a still larger number when the wound is due to shell fragment, there is a fracture of one or more of the ribs or the scapula.

Fragments of bone of varying size are carried into the chest, when they remain in the lung itself or in the pleural cavity, especially in the cul-de-sac above the diaphragm. Each fragment becomes itself a projectile driven with force into the tissues, carrying with it a capacity for infection and inflicting grave injury upon all the parts through which it tears its way.

In severer cases a part of the chest wall may be destroyed, being driven inwards by a large fragment of shell, or being swept away by a glancing blow.

(2) *The Injured Lung.*—The effects produced on the lung are closely compatible with those produced in other parts of the body by the various forms of missile. The wounds of entrance and exit are very similar to those seen in other soft tissues of the body. The size of the wound actually depends upon the size and shape of the fragment which has caused the injury.

Generally speaking, the entrance wound is small, and may be even punctate, the orifice of exit is larger, more irregular, and shows signs of greater destruction.

Along the track of the missile there are all the signs of a diffused injury, the parts around are bruised and lacerated, there is a surrounding haemorrhagic infiltration, often of wide extent. That portion of the lung tissue which directly abuts on the track is devitalised or even necrotic, and offers therefore the most favourable opportunity for bacterial invasion and growth.

It is important to notice that lung wounds differ from wounds of the solid viscera in so far that there are no fissures radiating from the main track and that there are no hidden recesses or pockets. Several tracks may be found in close proximity, but this is only when several fragments of metal have entered or when spicules of bone have been indriven.

Bronchi of large or medium size generally escape injury. There is always considerable haemorrhage from injury to the blood-vessels, and the haemothorax which results is derived from the bleeding lung vessels and not from the parietes.

The injury to the damaged lung is not confined to the track of the missile and the parts immediately adjacent. There may be sub-pleural haemorrhage by "contre-coup" in the upper lobe if the lower lobe be injured or *vice versa*, and these haemorrhages probably account for the recent pleural adhesions which are found in areas quite distant from the

track of the missile. Sometimes there is a diffuse haemorrhagic infiltration of the whole lung, and this is believed to occur in wounds which have been inflicted at close range.

(3) *The opposite Lung and Mediastinum.* — It is now recognised that in unilateral chest wounds the opposite lung suffers damage also, and the more severe the original wound, the more likely is this to occur. The injuries to the opposite lung consist in small or large haemorrhages beneath the pleura or in the substance of the lung. They are followed by adhesion between the visceral and parietal pleura, and the lung may present all the appearances of a broncho-pneumonia at one point or at many. The increased activity imposed upon the unwounded lung renders it an easy prey to inflammatory lesions, and the presence of infected mucus in the trachea may lead to an inhalation of purulent or septic material. Collapse of the lung, partial or massive, may occur.

Haemorrhage and effusion may occur into the mediastinal cavities or into the pericardium. Autopsy sometimes reveals bruising of the heart when there is no penetration of the pericardium, and this is to be explained by the missile striking the side of the mediastinum and rebounding.

In open wounds of the chest with a pneumothorax on the affected side and collapse of the injured lung, the mediastina and contents are displaced towards the opposite side. A large haemothorax with closed wounds results in a similar displacement.

Haemorrhage and Haemothorax.—If the larger vessels in the mediastinal cavities or in the root of the lung are divided the haemorrhage is so copious and so rapid that death results at once. In the cases not immediately fatal, the blood comes in the great majority of cases from the lung tissue.

Henry and Elliott came to the conclusion from post-mortem experience that the bleeding had been of pulmonary origin in the great majority of cases.

The amount of blood extravasated into the pleural cavity varies very much from a few ounces up to 4 or 5 pints. The escape of blood is hindered and eventually arrested by the collapse of the wounded lung and by the pressure exerted by the blood which has already escaped into the pleural cavity.

Infection.—The pleural cavity may become infected in various ways:

(1) The missile and portions of clothing and splinters of fractured rib carried by it into the pleura or lung may form centres of infection.

(2) A wound opening directly into the pleural cavity and through which air is sucked will always lead to infection.

(3) The wound in the chest wall is already infected, and when the chest muscles are badly lacerated it may become the seat of septic processes which ultimately extend into the pleura. According to Duval, the organisms responsible for infection are as follows:

A. Aerobic—

1. Derived from the respiratory tract:
   - Pneumococcus.
   - Staphylococcus.
   - Bacillus tetragenus.
   - Bacillus of Pfeiffer.
2. Derived from the wound:
   - Streptococcus.
   - Bacillus coli.

B. Anaerobic—

- Bacillus of Welsh.
- Bacillus sporogenes.

The most common association is that of the Bacillus coli with the gas gangrene bacillus.

The frequency of infection may be gauged from the figures given by Captain H. Henry. Out of 500 specimens of fluid obtained by tapping in the ordinary routine of work, 195 were

found to be infected, and of these 87 were infected with anaerobic organisms.

The infecting organisms may be distributed from the first throughout the bulk of the fluid, or they may be retained for a time in the fibrinous masses at the bottom of the pleura, being eventually distributed throughout the fluid by the respiratory movements. This accounts for the fact that punctures made for diagnostic purposes, if made into the upper fluid parts, are often negative, while there is really a heavy infection of the lower fluid.

Clinical History.—Men wounded in the chest will tell you that their first sensation was that of "their breath being knocked out of them," as they describe it. This was followed by a feeling of asphyxiation, and then there was the establishment of a more or less troubled respiration. When these cases come under observation, the majority still show pronounced respiratory distress, and in some cases the distress is intense.

Severe mental anxiety is sometimes a noticeable feature. The usual signs of haemorrhage are present in a greater or lesser degree.

Respiration and pulse rate are invariably quickened, and the breathing is laboured and attended with pain. Haemoptysis is a constant feature when lung tissue is penetrated, but it never assumes alarming proportions among men who reach Casualty Clearing Stations.

Physical Signs.—The patient should not be subjected to any detailed examination until the shock and exhaustion of his journey has to some extent abated. At the end of one hour or so, he is generally so much improved as to permit of examination, and if it is intended to carry out an early operation, a meticulous investigation should be made.

To begin with, a survey is made of the whole body and all wounds are examined. It should be remembered that injury

to the contents of the chest may be caused by missiles entering another part of the body, such as the face, the neck, the shoulder, and even the pelvis or abdomen. The body is searched for complicating wounds, especially with regard to abdominal or spinal injury. Local evidence is sought for regarding haemothorax, pneumothorax, collapse of lung, displacement of heart, and the position and size of the foreign body.

Much may be learned by careful inspection of the movements of the chest as a whole. Nearly always the wounded side expands less, and if there is entire collapse of the lung the affected half of the chest is retracted and motionless. If there is partial collapse of the lung on the unwounded side, a portion of the chest wall on this side is often retracted and motionless: sometimes there is an inspiratory retraction.

Inspection may also reveal an obvious displacement of the apex beat of the heart. There is generally some escape of blood from the wound of the parietes, and if the wound is an open one and has not previously been closed there is the sucking in and the expelling of air.

Palpation shows that on the affected side vocal fremitus is feeble, if indeed it is present at all.

On the unwounded side vocal fremitus is diminished over any area of the lung which may be collapsed.

Over the base and back of the chest on the affected side there is usually an area of total dulness indicating the extent of the effusion.

By auscultation no breath sounds can be heard at the base on the affected side, but in the upper part of the chest bronchial breathing with crepitations or râles are very frequently present. Vocal resonance is generally absent over the lower part of the chest.

Immediately above this area there is a portion where aegophony is present. Sometimes it is exceedingly difficult to interpret the chest physical signs.

Vocal vibrations are not always diminished over a haemothorax, and sometimes they are even increased.

Early pneumothorax due to the injury to the lung passes off in a day or two as a rule, but occasionally it increases and causes complete collapse of the lung, with great distress to the patient. The signs are full or excessive expansion of that side of the chest, boxy resonance over the whole or large part of the affected chest, absence of breath sounds, displacement of the heart to the opposite side, a rapid pulse, and great distress in breathing.

It is most important to ascertain the position of the heart. In many cases the apex beat can be felt or the cardiac dulness determined, but in some instances weakness of the beat prevents the first observation being made, while a traumatic pneumothorax abolishes the second. Auscultation will then usually enable one to say whether the heart is much displaced, but sometimes the sounds are inaudible. The determination ought to be made as accurately as possible, since the situation of the heart is not only an indication of present conditions in the chest, but any subsequent change in its position is of great importance in the early diagnosis of sepsis.

This early examination should conclude with an X-ray examination. Full-size stereoscopic plates showing both sides of the chest and the diaphragm should be taken. These will give information regarding:

(1) The position and size of the foreign body.

(2) The existence and extent of haemothorax and pneumothorax.

(3) The condition of the opposite lung, cardiac displacement, and movements of the diaphragm.

If localisation of the foreign body proves difficult, it may be necessary to take repeated X-ray examinations. For this purpose an aluminium-topped combined operating and X-ray table of the type of the Bonnette Eclipse du Dr. Dessane is of the greatest service.

It is an advantage also to be provided with a sectional anatomical atlas.

The Treatment of Chest Wounds.—*Early Treatment.*—At the advanced dressing station these patients should be rested in the most comfortable position, and generally in the semi-recumbent one. They should be restored from shock as far as possible by means of hot drinks, by the application of heat, and to lessen the respiratory distress morphia should be given in an amount not exceeding half a grain. If there is an open wound of the parietes into the pleura, this wound should be closed in order to prevent air being sucked in as well as being blown out. When this point is not attended to, a positive pressure may be established (valve pneumothorax). The wound may be closed by inserting deep skin sutures without an anaesthetic, or by plugging the wound with gauze and covering the gauze with a firm application of strapping. The cases should be evacuated to the Casualty Clearing Station as soon as they are fit to stand the journey.

The Question of Primary Operation.—Soon after arrival at the Casualty Clearing Station the question has to be decided whether or not a primary operation is necessary.

There are certain cases which do not require early operation and these are now excluded. They, of course, form the great majority of the cases. They include:

(1) Small clean wounds, including through-and-through bullet wounds, without evidence of serious intrathoracic injury other than haemothorax.

(2) Cases in which a missile is retained which is only of small size.

(3) Cases in which the retained missile, though large, is in such a position that access will be both dangerous and difficult.

(4) Cases of uninfected haemothorax.

Having excluded these cases, there are those in which a

primary operation is indicated. They may be summarised as follows:

(1) Ragged wounds of the parietes with or without compound fracture of the ribs.

(2) Open wounds of the chest wall through which air is being pumped in and out of the pleural cavity.

(3) Retention of a foreign body in an accessible position.

It must be recognised, however, that in this group there are certain contra-indications to immediate operation.

(1) Shock and collapse.

(2) Collapse of the opposite lung. In this condition the administration of an anaesthetic and opening of the chest may be fatal.

The Operation.—*Anaesthetics.*—Local anaesthesia has the advantage that it obviates irritation of the opposite lung, and also that the patient is able to assist at the completion of the operation by partially expanding the injured lung before final suture. If the full benefit of local anaesthesia is to be obtained, the patient should first be rendered drowsy by the administration of a preliminary hypnotic—$\frac{1}{2}$ or $\frac{2}{3}$ grain of omnopon with $\frac{1}{150}$ grain of scopolamine is given one hour before operation, and if drowsiness does not come on in half an hour, $\frac{1}{3}$ grain of omnopon is given.

Probably the best local anaesthetic to employ is a 1 per cent solution of novocaine with or without adrenalin (10 minims of adrenalin to each ounce of the solution). The solution is infiltrated around the wound and the intercostal nerves are blocked.

The nerves are blocked immediately behind the angles of the ribs: the intercostal spaces affected and those immediately above and below are infiltrated. For making the injection Gray's syringe is suitable.

During the intrathoracic stage of the operation it is advisable to give the patient a general anaesthetic, and for

this purpose nitrous oxide and oxygen is undoubtedly the best.

There are circumstances in which it is imperative to administer a general anaesthetic throughout—in cases of multiple wounds for example. It will be found that these patients take a general anaesthetic satisfactorily, provided that there is no damage or collapse of the opposite lung. Nitrous oxide and oxygen is probably the best anaesthetic to use; if not available, chloroform may be given with oxygen through a Shipway apparatus. Ether is contra-indicated except in those instances in which it may be given by an intratracheal apparatus.

Position.—For operation the patient should be maintained with the injured side dependent, and in the majority of cases a half-sitting position is the most comfortable.

Technique.—The first thing to be done is excision of the wound of the soft parts unless the wound is small and clean. Even rifle bullet wounds, if infected, should be excised, as otherwise they will suppurate and infection may easily extend into the pleural cavity. The excision of the wound should be extended down to the ribs. If the bone is broken, splinters should be removed, the ragged edges of the bone cut cleanly away, and all dead tissue excised. Any bleeding which there may be from intercostal vessels is arrested.

The wound may extend into the chest and yet no foreign body be *in situ.* If so, the wound in the pleura is enlarged so as to permit admission of the hand. Any foreign body or loose splinters of bone lying free in the pleura or sticking into the pleura are removed. Free blood in the pleural cavity is mopped up with strips of gauze which have been wrung dry out of warm saline solution. The surface of the lung is examined. If there is a bleeding wound of its surface, haemorrhage is arrested and closure of the wound effected by interrupted catgut sutures. Should it happen

that the edges of the wound are obviously infected, they are excised and sutured. The thorax is now closed in layers—pleura to pleura, muscle to muscle, and skin to skin. The closure of the parietal pleura is the most difficult part of the operation, the edges are united by fine interrupted catgut sutures and coaptation is facilitated if the membrane is stripped from the chest wall for some distance around the wound.

Retention of a Foreign Body.—More importance should be attached to the damage caused by the missile and the infection carried in by it than to retention of the foreign body itself. When it is decided that removal of the foreign body is essential, the operation may be undertaken either through the wound or by a fresh thoracotomy. If the route chosen is through the wound, the procedure is similar to that detailed for excision of the wound, but instead of only removing the broken ends of the rib a resection of four or five inches of the bone is necessary.

If it is decided to open the chest by a fresh thoracotomy the following technique may be adopted. A curved incision five or six inches long is made along the line of the fourth rib, the centre of the incision being in the mid or in the anterior axillary line. The fibres of the pectoralis major are split and the pectoralis minor separated from the rib. The rib and its costal cartilage are exposed for about five inches and haemorrhage is carefully arrested so as to give a perfectly dry field. An incision is made through the periosteum midway between upper and lower borders, and the membrane is stripped from both surfaces. A Doyen's curved raspatory is useful for this purpose. The costal cartilage is cut through, and the rib is divided posteriorly. Cowell has suggested splitting the rib longitudinally so that the upper and lower portions can be subsequently reunited in the repair of the chest wall.[1]

[1] *B.M.J.*, Nov. 3, 1917, p. 581.

The pleura is incised along the line of the rib, and a retractor or rib spreader is introduced in order to open up the wound. The hand is now passed into the chest cavity. Adhesions of the lung to the parietal pleura may be encountered and these are separated. The collapsed lung is seized with the fingers or forceps and drawn up to the anterior wound, and gradually it is coaxed out of the wound. It is surrounded as it appears by warm cloths soaked in normal saline solution.

When a lobe of the lung is delivered it is carefully palpated. Any foreign body embedded in it is felt at once, the part of the lung containing it is made prominent, the lung tissue lying over it is incised, the foreign body removed, and the wound sutured.

Deep sutures of catgut are passed through the lung substance and with gentle traction act as a haemostatic.

Precision in suture is most desirable, and, if necessary, very fine catgut sutures may be used to secure accurate apposition of the pleural edges.

When the foreign body is removed and suture completed, the lung is replaced, the cavity of the pleura most carefully emptied and dried, the retractor removed, and the pleura sutured. The rib, if it has been turned back, is replaced, the muscles are carefully sutured, and the wound edges approximated without drainage. It has been advised that after the dressing has been applied a two-way needle be plunged into the chest and air and any free blood extracted therefrom.

Post-operative Treatment.—The patient is kept at rest in the position he finds most comfortable for himself. At first it is usually a semi-recumbent position and later a semi-sitting posture. It is important to keep the injured side dependent. Undue restlessness is prevented by the administration of small doses of omnopon. Many of these cases are successfully nursed in the open air.

Careful watch should be kept for the accumulation of effusion into the pleural cavity, and on the least suspicion of such an accumulation occurring the pleura is punctured with an exploring needle. If exploration shows that the fluid is infected, infection may be kept in check by repeating the aspiration every second day or even oftener. In many cases so treated the temperature falls, the lung expands, and the fluid ceases to accumulate. If bacteria are present in large numbers and an increasing and a general infection is appearing, it may be necessary to remove some of the stitches from the wound and to insert a tube into the pleural cavity.

If there is much cough and expectoration, it is indicated to give a sedative expectorant. Equal parts of Tinct. Camph Co. and Syrup of Tolu is excellent ($\frac{1}{2}$ to 1 drachm). If there is much spasmodic dyspnoea, a few minims of Liquor morphinae acetatis is useful.

Sometimes there is a difficulty in expectoration, in which case a stimulating expectorant with 3-4 grains each of carbonate of ammonium and iodide of potassium is indicated.

With a view to the prevention of septic broncho-pneumonia it has been suggested to give 2 minims of creosote in mucilage three times daily from the time of admission.

The Treatment of Non-Infected Haemothorax or Pneumothorax.—The treatment of a simple non-infected haemothorax or pneumothorax consists in merely aspirating the blood from the pleural cavity. If more than two finger-breadths of fluid can be made out, aspiration should be done. This should be carried out on the second or third day. It should be done slowly, taking fully thirty minutes, and only moderate suction should be employed. The aspiration is done by means of the ordinary aspirating apparatus. A local anaesthetic may be injected into the skin and muscles in order to make the puncture as painless as possible. After the injection of the anaesthetic a tiny incision may be made through the skin so

that the round canula is not gripped by it. It is important to use a fair-sized canula as small needles are very easily blocked. If during the aspiration the patient begins to suffer pain in the chest and complains of shortness of breath, the trochar should be disconnected from the bottle and a little air allowed to enter the pleural cavity. It will then be found that more blood can be withdrawn before the pain and distress return. If in addition to the blood there is a large amount of air in the pleural cavity, the bottle should not be exhausted before the trochar is connected but should be exhausted gradually during the whole aspiration, as the sudden evacuation of a large quantity of air when the tap is opened may cause alarming symptoms.

There are some cases in which, though there is evidently a large effusion, very little fluid can be evacuated by aspiration. In these cases the blood has probably clotted. Further attempts at aspiration should be made on subsequent days with the help of the X-rays. If these are still unsuccessful, the case should be treated by opening the chest, removing all the blood and clot, closing the pleural cavity, and aspirating the air. This is necessary because a clotted effusion may lead to a very dangerous sepsis.

The Treatment of Infected Haemothorax.—Apart from the examination of the pleural fluid, there are certain clinical features which indicate the presence of infection. The patient looks unwell, is restless and sleeps badly, the tongue is dry, and the appetite is bad, the temperature usually rises, and the pulse and respiration become more rapid. In many septic cases gas forms in the effusion and a pneumothorax is produced.

It is inadvisable to lay too much stress on bacteriological evidence. It is not infrequent for the exploring syringe to draw off a sample of fluid which is sterile, though septic infection has occurred in another part.

Infections differ much in danger. The presence of a few organisms is not sufficient ground for resection of ribs. Streptococci, if numerous, and especially if haemolytic, are the most dangerous. A mixed infection is also dangerous. Marked haemolysis of the fluid is very suggestive of infection.

The inclusion of the bacteria in the leucocytes is an important indication, as if intracellular inclusion is present it is possible that resection may not be necessary.

When the effusion is not foul smelling and when the clinical symptoms do not show infection, a number of cases have been successfully treated by repeated aspiration. In the event of either of these indications being present, a portion of rib is resected and clot and fluid blood are removed, the cavity is washed out with warm saline and dried with gauze. The chest wound is then closed, and forty-eight hours later the chest is aspirated and serum and air removed. If there is a recrudescence of infection and general symptoms, it is wiser to drain the pleura. It has been recommended to leave a quantity of antiseptic fluid in the pleura in these infected cases. Eusol and flavine have been tried. The method is of very doubtful value.

Subcutaneous Emphysema.—This is not infrequent and it is usually quite harmless even when extreme. It often renders examination very uncertain. There is no special treatment indicated and it eventually disappears spontaneously.

Date of Evacuation from Casualty Clearing Station.—Cases of small haemothorax who are not distressed may be safely evacuated seventy-two hours after the injury. A patient with a large haemothorax should remain for at least twenty-four hours after aspiration, and if then comfortable may be sent to the base. Cases which have had severe operations should be retained for ten days at least after operation. Patients who have suffered from pneumonia, bronchitis, haemorrhagic congestion, or collapse of the unwounded lung should not be

allowed to travel until recovery from these conditions has taken place.

Prognosis and Mortality.—Wounds of the chest form about 2 per cent of all wounds: a through-and-through bullet wound is the most favourable, shell wounds are the least promising.

If the diaphragm is perforated the prognosis is less favourable, and if the spine is injured the outlook is very grave.

The mortality of chest wounds in the Casualty Clearing Station varies from 7 to 19 per cent.

Of those who die in the Casualty Clearing Station about half die in the first 24 hours. They succumb to shock, haemorrhage, or injury to a vital organ.

Of the remaining deaths septic infection of the pleural cavity is the most frequent cause.

CHAPTER IX

ABDOMINO-THORACIC WOUNDS

Abdomino-Thoracic Wounds.—This type of wound is more common than one would imagine. In 839 cases of abdominal wounds there were 101 cases in which the missile penetrated both thoracic and abdominal cavities, a ratio of about 12 per cent.[1]

The wounds are mostly confined to one side of the diaphragm: those cases in which both sides of the diaphragm are involved are generally rapidly fatal.

The diaphragm lesion may be a puncture, a linear tear, or an irregular gaping hole. The wound is generally on the sloping muscular portion, and in a large proportion it is that part of the diaphragm in contact with the thoracic wall which is involved.

Naturally the extent and nature of the lesion depend on the size and shape of the missile and on its inclination to the plane of the diaphragm at the point of impact. Fractured ribs are sometimes responsible for a certain amount of damage.

Herniated Organs.—When the left half of the diaphragm is injured there is a tendency for herniation of the abdominal viscera into the chest to occur. The omentum is the organ most commonly involved, and the spleen, stomach, left transverse colon, and small intestines are also found.

[1] Cuthbert Wallace, *War Surgery of the Abdomen*, p. 119.

On the right side the close relationship of the liver to the under surface of the diaphragm prevents herniation.

Abdominal Organs wounded.—This is an important question to decide because it has a bearing on the subsequent treatment to be adopted, and, if operation should be necessary, on the route to be employed. When the wound affects the right side, the liver, of course, is almost certain to be involved. On the left side the spleen is most frequently damaged. The colon, stomach, and kidney are involved in a lesser proportion. It is important to remember that coils of jejunum lying in the left hypochondrium are wounded in a certain proportion of cases.

Treatment.—It is very necessary to know the track of the missile and the situation in which it is lodged, and in these cases a good X-ray photograph is of inestimable value.

If the wound involves only the neighbourhood of the diaphragm, a transpleural incision is the best: through it the diaphragm is repaired and an extension of it permits of inspection of the abdominal viscera when this is necessary.

If the track of the wound is such that both abdominal and thoracic viscera are certainly involved, the question has to be decided whether the thoracic wound demands treatment, and if so whether or not it should take preference over the abdominal wound. In such cases the following recommendations may be useful:

(1) If the thoracic wound is small, it may be disregarded and immediate attention given to the abdominal condition.

(2) If there is an open, blowing wound of the chest wall, if there is respiratory distress, or if the hypochondrium is alone involved, the pleural condition should first be attended to and the transpleural incision afterwards enlarged to expose the abdominal lesion.

(3) In other cases the abdominal condition should first be attended to, the lung and diaphragmatic lesions being dealt

with subsequently if it is considered advisable and if time permits.

The question arises as to the suture of the wound in the diaphragm. There are certain distinct advantages in closing the wound.

(*a*) It is said that respiration becomes easier.

(*b*) The blood is retained in the pleural cavity and natural arrest of pulmonary bleeding may thus be favoured.

(*c*) Herniation is prevented or reduced.

It is universally accepted that for suture of the diaphragm the transpleural route should be chosen. If the operation has been so planned that the chest condition is being first dealt with, suture of the diaphragm will follow as a matter of routine, but if coeliotomy is the primary step the insistence upon suture of the diaphragm in all cases will mean a lengthening of the operation which may be prejudicial to the wounded man.

Diaphragmatic Hernia.—These cases occur as complications of abdomino-thoracic wounds.

The instances recorded have all been left-sided. The herniation may occur coincident with the wound (the immediate type); it may occur within a short time of the injury, generally within ten days (intermediate type); or it may only occur after some time has elapsed (the remote type). The clinical features are often obscure and puzzling. There is an increase of pulse rate and of respiration rate. There are certain individual symptoms dependent upon the viscera which have become herniated. If the stomach is herniated, there is pain on taking food, difficulty in swallowing which is overcome by assuming a dorsal or left-sided posture, and vomiting. If the colon is herniated, there are attacks of abdominal pain and constipation, with intervals of comfort.

The physical signs are generally limited to the chest unless intestinal obstruction has resulted: they are dulness and

absence of breath sounds; feeble respiratory murmurs and increased resonance; tinkling, gurgling, or splashing sounds.

An X-ray examination will show absence of the usual lung shadow and an alteration in the position, form, and mobility of the vault of the diaphragm.

If the stomach is the organ which is herniated, a bismuth meal makes the diagnosis clear provided the stomach is herniated at the time.

Treatment.—If the diagnosis is clear and there are no obstruction symptoms, the diaphragm is approached by the transpleural route, the hernia is reduced, and the wound in the diaphragm sutured. If the diagnosis is uncertain, and if acute symptoms are already present, it is advisable first to open the abdomen by a paramedian incision. The condition of affairs is ascertained and reduction is secured. It may be possible to close the rent from the abdomen; failing this the chest is opened in a favourable position and the diaphragm wound sutured.

CHAPTER X

INJURIES TO THE HEAD

THE frequency of head injuries has been considerable because trench warfare has played such a leading part in the military scheme. Trench defence has meant the greater exposure of the head, neck, and upper parts of the body in proportion to the other regions.

With the introduction of the steel helmet there has come an improvement. The relative number of head wounds has been reduced, and the proportion of penetrating as compared with non-penetrating wounds has been diminished.

At one time it was thought that head injuries would necessarily carry in their train a terrible list of mentally unfit, minor cases of slight mental and physical incapacity, and others of epilepsy, hemiplegia, blindness, and insanity. Fortunately such fears have not been fully justified, and though it is yet too early to come to any opinion, the feeling generally is that the possibilities of serious later complications have been exaggerated. However, there is necessarily a very large early mortality, and recent work indicates that careful attention to operative technique can effect a very real reduction in this mortality (Cushing).

Nature of the Injuries.—Apart from scalp wounds the majority of gunshot wounds of the head are essentially compound fractures complicated by more or less serious injury to the brain and its membranes.

Although a certain amount of overlapping is inevitable, it is possible to classify head injuries into certain groups:

(*a*) Scalp wounds without injury to the bone.

(*b*) Fissured fractures.

(*c*) Depressed fracture of inner table without gross defect of outer table.

FIG. 44.—Gutter wound of scalp, with gutter fracture of the vault.

(*d*) Impact fractures in which both tables are driven inwards, with or without injuring dura, and foreign body is not retained.

(*e*) Gutter or tangential fractures.

(*f*) Penetrating wounds.

(*g*) Perforating or through-and-through wounds.

The Bone.—It is the exception to find simple fissuring of the skull as a result of the direct impact; it is constantly

found, however, radiating from a perforating wound. A direct fissured fracture is conceivably the result of the impact of a spent missile. When the injuring missile has a greater force, an impact fracture may result and, depending upon the force of the blow, the dura is or is not perforated. The resiliency of the outer table of the skull is such that in many cases it shows no defect, while the more brittle inner table is shattered and driven inwards upon the dura.

In the great majority of penetrating wounds bone fragments are driven into the brain. The velocity of the missile is

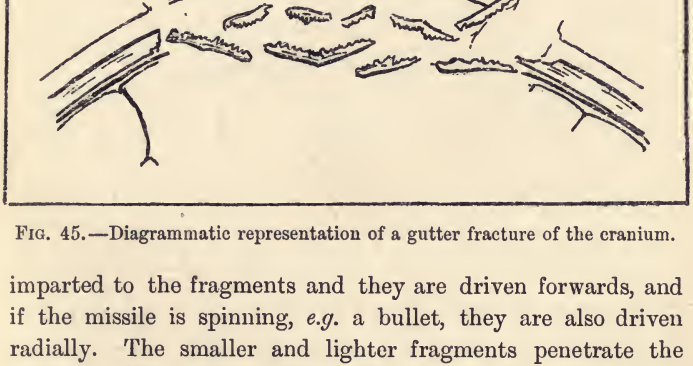


FIG. 45.—Diagrammatic representation of a gutter fracture of the cranium.

imparted to the fragments and they are driven forwards, and if the missile is spinning, *e.g.* a bullet, they are also driven radially. The smaller and lighter fragments penetrate the furthest. The actual extent of the defect in the skull depends to a great extent upon the shape and size of the missile, but it should be remembered that the exit opening of a penetrating wound is often of very small dimensions as compared with the entrance wound.

The Brain.—In the immediate vicinity of the wound track the brain substance is destroyed, vessels are torn with consequent haemorrhage into the meningeal spaces, into the ventricles, and into the brain itself. More distally there are

many punctate haemorrhages diminishing in size the further they are distant from the track of the bullet. The velocity of the missile is transmitted also to the brain, and it is likely that impact waves pass in all directions through the substance of the brain and its fluid contents.

The transmission of such waves through the cerebro-spinal fluid, and especially through the ventricular spaces, may paralyse respiratory, vasomotor, and cardiac centres. Of these centres the vasomotor is the most sensitive.

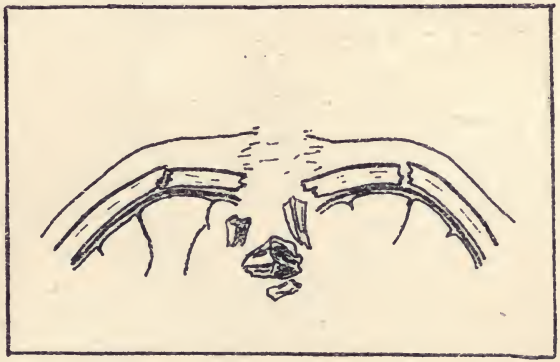


Fig. 46.—Diagrammatic view of penetrating wound of skull.

Infection.—Each fragment of bone driven into the brain carries with it a certain degree of infection, more especially when the injury is situated in the region of the hairy scalp, hair or portions of headgear being carried inwards along with the missile.

The use of the steel helmet has considerably reduced the proportion of badly infected wounds.

The importance of sepsis as a factor is almost wholly dependent upon the integrity of the dura mater, and so vitally important is this membrane as a barrier against intracranial infection that it is rarely justifiable to incise it in the presence

of an open wound. Even if the dura is already lacerated, the sub-arachnoid space often escapes direct infection owing to the rapid formation of adhesions between the dura and the pia-arachnoid. These adhesions form in the course of a few hours (Sargent).

This fact is of great importance in the operative treatment, and will be alluded to later.

Clinical Features.—*Scalp Wounds.*—Beyond a certain loss of blood and some slight headache and dizziness, the injured man may be none the worse. In most cases, however, either through the direct impact of the missile or from concussion effects, the injury may result in a short period of unconsciousness, followed, perhaps, by symptoms of cerebral irritation, restlessness, excitability, and severe headache.

Fracture Wounds.—Before detailing the clinical features of these a word of warning is necessary. It is apt to be assumed that the symptoms which may exist at any given moment after the injury are related directly to some gross and visible lesion such as depressed and visible bone fragments or haemorrhage. This assumption may lead to the performance of an operation. In many cases operation is unnecessary because the functional disturbance is frequently not due to any pathological condition which can be directly affected by the operation. The lesions of the brain are coexistent with those of the scalp and bone, yet the two are quite independent.

It may be argued that one ought to discuss the clinical features according as they depend upon concussion, compression, or brain laceration. Theoretically this may afford a good classification, but in actual practice any such subdivision is impossible; pure concussion and pure compression practically never exist as distinct clinical features.

We have therefore decided to classify head injuries from the clinical point of view into three varieties.

Class A.—This variety shows a penetrating or perforating

wound of the skull. There is usually complete unconsciousness. The general appearance is one of pallor, and there is often profuse perspiration. As a rule the patient is irritable

Fig. 47.—Penetrating wound of skull with retained foreign body.

and restless, especially if disturbed in any way. The pulse is small and rapid. The blood pressure is low. The respirations are rapid and sometimes stertorous.

According to the position of the injury, focal signs may or

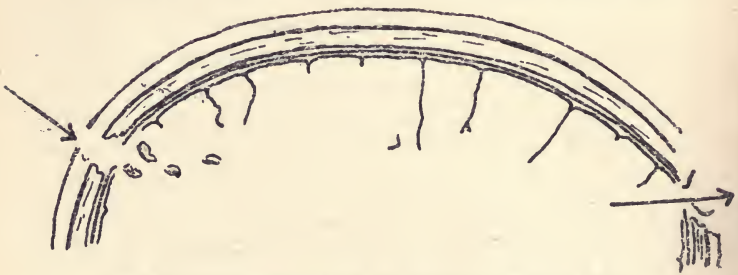


Fig. 48.—Diagrammatic view of perforating wound of skull.

may not be present, and any paralysis which exists is generally flaccid in type. Spasticity with increase of reflexes is rare. This class of case is generally unpromising.

In wounds involving the longitudinal sinus there are features of general spasticity: the so-called "sinus syndrome of spasticity."

Class B.—There is a wound of the skull, but in many cases of this class the dura is uninjured, while in others the wound though penetrating involves a so-called "silent" area of the brain. The patient is often conscious, though he remembers nothing of his injury, and his intelligence is still clouded. His general appearance is good. Very often the face is flushed, severe headache is complained of, and there is frequently some sickness.

A most important and distinctive feature is the slow full

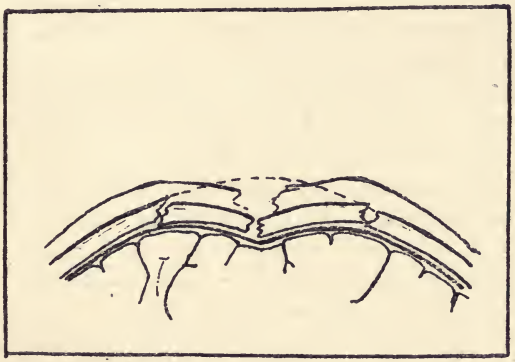


FIG. 49.—Impact fracture of skull with uninjured dura.

character of the pulse, and with this there is a normal or raised blood pressure.

Focal symptoms may or may not be present. In this class of case the prognosis is generally good.

Class C.—Under this heading we include those cases which show no wound, and which demonstrate the features generally associated with a fractured base.

The Examination of the Patient.—*Neurological and X-ray Examinations.*—No serious cranial operation should be undertaken without a preliminary neurological study. This, unhappily, is a rule which is too frequently broken. Apart

from the clinical interest and importance, the neurological findings may be most helpful to the operator. They may guide him to the justifiable opening of intact dura during the course of the operation, and secondary findings by comparison with the original may indicate the need of a later operation for relief of a cerebral abscess.

X-ray examination is of course invaluable. By it the localisation of the penetrating missile is determined, and the detection and enumeration of indriven bone fragments is made possible.

Examination of the Blood Pressure.—This is a most important detail to observe. A low blood pressure contra-indicates immediate operative interference, and operation should be deferred until repeated blood pressure examination shows that the pressure has risen and is being established.

The Prognosis of Head Injuries.—Certain classes of cases are necessarily fatal in a few hours, as in very severe wounds caused by large pieces of shell in which an extensive part of the skull and brain is blown away, or when a rifle bullet causes explosive intracranial effects.

Apart from these cases, it is remarkable that the actual injury to the brain is in itself rarely fatal. The dominant factor in the prognosis is the development of infection, and here it is that the question of an intact dura becomes of such vital importance. With reference to statistics it appears that a streptococcal infection is followed by the largest mortality.

The position of the wound is important. Antero-posterior wounds near the base of the skull, even if small, are exceedingly fatal. Transverse wounds near the base, and wounds of the base with entrance in the orbit, are likewise very fatal. The character of the pulse is a reliable indication of the prognosis. A rapid pulse is a most unpromising feature, while a slow pulse is distinctly favourable. It must be stated in this relation that a slow pulse is not necessarily a sign of compression, as it con-

stantly is found in those wounds associated with large exposure of the brain.

The Treatment of Head Injuries. — On arrival at the Casualty Clearing Station the patient ought to be allowed to rest in bed for two or three hours, and during this period suitable treatment is carried out for any shock or collapse which is present. During this period the local and neurological examinations are carried out and X-ray photographs are taken. The whole scalp is shaved before operation.

The Selection of Cases for Operation.—All scalp wounds are submitted to operation, the wound being excised and sutured. In cases in which the skull is fractured or penetrated some consideration is necessary of the method of the selection of cases for operation.

Group I. *Cases in which an Immediate Operation is Unwise.* —(*a*) Those patients whose general and local conditions are hopeless. Here it is unwise to come to any immediate final determination. A delay of twenty-four hours with appropriate treatment and observation is indicated. At the end of this time the patient's improvement and the knowledge which the observer has meantime obtained by X-ray examination, etc., may justify interference.

(*b*) This group consists of those who have reached the Casualty Clearing Station some considerable time after the infliction of the wound, and who already show acute and active sepsis of the scalp wound. In these cases, before opening the skull, it is advisable first to clean and drain the superficial tissues. Any more radical operation is almost certain to be followed by a fatal extension of the sepsis to the intracranial tissues.

Group II. *Cases which demand an Immediate Operation.*— There are cases which demand the earliest possible operative interference.

(*a*) Cases which show evidence of local cerebral irritation.

(*b*) Cases which show signs of cerebral compression, notably severe headache.

(*c*) Cases of coma and slow pulse.

(*d*) Cases of progressive haemorrhage from meningeal vessels or sinuses.

In these two groups the evidences for a decision are generally clear, and in regard to the large number of cases which do not come under either heading it is advisable to adopt a radical principle and to operate on every case where the skull is fractured or penetrated.

Preliminaries to Operation.—We have mentioned the importance of the neurological and the X-ray examination, and the necessity of shaving the entire scalp. About an hour before operation a sedative is given, a third of a grain of omnopon usually being sufficient, though this may be repeated if the patient is very restless.

Anaesthesia.—Local anaesthesia has proved of value and presents definite advantages. A solution of 1 per cent novocaine and adrenalin (15 minims to 30 c.cm.) is employed. The solution is injected in the sub-aponeurotic layer into the area involved in the operation. The advantages are that haemorrhage is reduced to a minimum, the head can be conveniently elevated, the patient may even be operated on in a sitting position, thus diminishing intracranial tension; if it is advisable to raise the intracranial pressure the patient can be made to do so by coughing, and post-operative shock and vomiting are largely abolished.

There are cases, however, which demand the use of a general anaesthetic—restless, fractious, and timid patients. Gas and oxygen answer well in the morphinised patient, or ether may be administered by the Shipway apparatus. There are great advantages in the use of intratracheal anaesthesia if the apparatus is available. Chloroform should be avoided.

Operative Technique.—The whole scalp having been shaved

and cleansed, the first step in the operation is the excision of the scalp wound. This of necessity is infected, and the greatest care must be taken to avoid soiling of the resulting wound by employing clean instruments, towels, etc., for the further stages of the operation.

Incision.—The best incision to expose the damaged bone is a subject of difference of opinion. Some prefer to enlarge the original wound, others feel that the turning down of a flap gives the best exposure. For ragged or gutter defects over the vault the tripod or three-legged (Isle of Man) incision gives excellent access. When the scalp wound is not too extensive we have favoured the turning down of a flap. Haemorrhage from the scalp wound is controlled by the infiltration for the anaesthesia and by compression, mallet head forceps being particularly useful. If a flap exposure is employed, a light intestinal clamp applied across the base controls the bleeding, and sometimes an elastic tourniquet is an advantage.

FIG. 50.—"Isle of Man" skin incision.

The Trepanation.—Adequate access to the damaged bone having been obtained, the next step consists in removing sufficient bone to expose the healthy dura for about half an inch around the wound in the meninges. The method usually adopted is to make with a trephine an opening to one side of the depressed area, and with rongeur forceps to nibble away fragments of bone until a sufficiently large opening is secured. This method has disadvantages. It means working across an infected field; the nibbling process is associated with a con-

siderable degree of trauma, and in certain areas of the skull there is great liability of the underlying dura being injured. A more simple and a more satisfactory procedure is to trepan the fractured area *en bloc*. The area of depressed bone is encircled with a number of small punctures made with a burr, and the primary openings are connected with a linear cut made with a De Vilbiss, a Dahlgren, or a Mentenovesi forceps. When the area has been encircled the bone disc is tilted out in one piece.

The *en bloc* method, introduced by Cushing, has none of the disadvantages of the nibbling method, and it possesses two distinct advantages. By replacing in a mosaic fashion the semi-detached fragments of bone, it is often possible to demonstrate whether or not fragments have been driven into the brain. The other advantage is that if a sinus happens to be torn by a bony spicule, the *en bloc* exposure of the field at once exposes the bleeding point.

The Treatment of the Dura Mater.—The dural opening, if obviously ragged and dirty, may be trimmed, but great care should be exercised in judging when this should be done. Such an excision is followed by troublesome bleeding, and the sub-arachnoid space may be opened and infected. It is most important to avoid disturbance of the subdural adhesions which have formed.

Bleeding from the membrane may be controlled by fine ligatures, by under-running with a round needle and fine catgut, by fascial or muscle graft, or by the temporary application of small compressible silver clips (Cushing).

Treatment of the Brain.—In penetrating cases the proper and thorough cleansing of the track in the brain is the most important step of the operation, remembering that the damaged brain must be treated with the greatest possible gentleness.

Pieces of metal and fragments of bone lying close to the surface are removed with forceps, each fragment being localised

gently with the fingers. The fingers should not be inserted for any depth into the brain as the disorganised cerebral tissue lining the track is, by so doing, pushed to a deeper level, whereas every effort should be made to get it out. Probably the best method of cleansing the track is by means of suction exerted along a soft rubber catheter (Cushing). By attaching a Carrel-Gentile glass syringe with a rubber bulb to the end of the catheter it is possible to suck up the softened brain into the catheter. The normal cerebral tissue adjoining the track is not liable to be drawn into the tube. The catheter determines the exact direction taken by the missile with the least possible injury to the brain. Sometimes small fragments

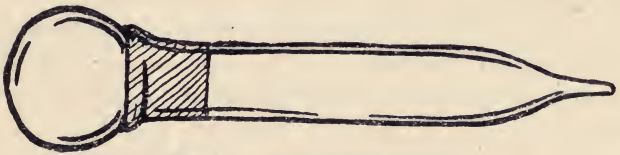


FIG. 51.—Carrel-Gentile syringe.

of bone come away into the eye of the catheter, and, as the track becomes cleaner and the tendency of the brain to herniate subsides, it is possible to pick out with fine forceps fragments of bone or foreign bodies which grating on the catheter has shown to be present.

Retained Missiles.—If the fragment of projectile be lying in the superficial part of the brain track, it is removed in the ordinary toilet of the wound. Fragments which lie at a considerable distance from the point of entry are almost invariably more deeply placed than the indriven fragments of bone, and their removal becomes a matter of extreme difficulty. Recent investigation shows that, in the majority of cases, foreign bodies left *in situ* give rise to no inconvenience. This consideration, together with those of difficulty in removal and the high mortality which accompanies the attempt, supports the opinion

held by many surgeons that a foreign body, unless easily accessible along a short track, should be left alone. Extraction with a magnet is the only justifiable method applicable to deep-seated bodies.

The Use of Antiseptics.—There are many advantages in conducting the intracranial portion of the operation under a stream of hot (115° F.) antiseptic lotion. Extruded brain matter is washed away, haemorrhage is checked, and the necessity for swabbing is avoided. It has been asserted that such a use of watery antiseptics is followed by oedema and swelling of the tissues, and a tendency to herniation. Di-chloramin T. in oily solution has been recommended as not possessing the above disadvantage. A small amount of the oily solution is injected along the course of the track through a small catheter, and just before the final closure of the scalp the dural surface of the wound is moistened with the same solution.

Closure of the Wound.—In closure of the wound there is one feature which should always be kept in mind. It is this: cover up the brain at all costs in the first instance, and if direct approximation be impossible, plastic flaps must be employed.

It is rarely possible to close the wound in the dura mater, but if this is possible it should be done, using interrupted sutures of catgut or fine silk. If exposure has been gained by means of a flap, the local excised scalp wound should, if possible, be closed before the flap is replaced. We have found it an advantage to close the deep surface of the local scalp wound by interrupted catgut sutures which pass through the deeper layers of the scalp without involving the skin. When the flap has been sutured in position, the skin edges of the excised wound are brought together superficially with interrupted silkworm-gut sutures. If access has been gained through the original wound, and there is a considerable defect,

the usual incisions of plastic surgery for sliding flaps is necessary. It may be necessary to close the excised scalp wound by some similar method. A gaping scalp wound may often be closed by cutting scalp flaps on the bevel (see diagram).

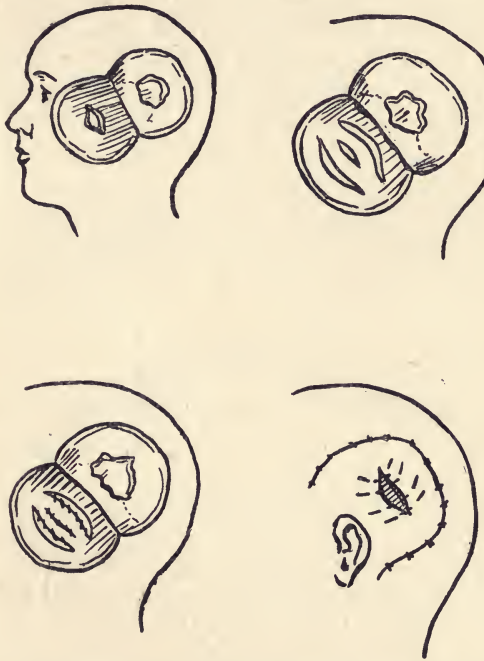


FIG. 52.—Diagrammatic view of the method of closure of the deep surface of the excised scalp wound.

Exposure of bone is thus avoided, and the defect is firmly repaired.

In cases which have not become definitely infected it is important to secure as complete a closure of the scalp tissues as possible. When sepsis has already obtained a firm hold, drainage must be provided. For the purpose a narrow roll of

rubber is best. It is brought from the dural opening (without entering the brain track) beneath the scalp and out through a part of the incision removed from the sutured original wound.

Modifications of Operative Treatment to meet Special Conditions.—*Fissured Fractures.*—In a number of these immediate trephining is not indicated, and the treatment is that applicable to any infected scalp wounds, namely, excision and suture. Such a wound generally heals rapidly, and if any operative interference later becomes necessary, the operation is done in an aseptic field.

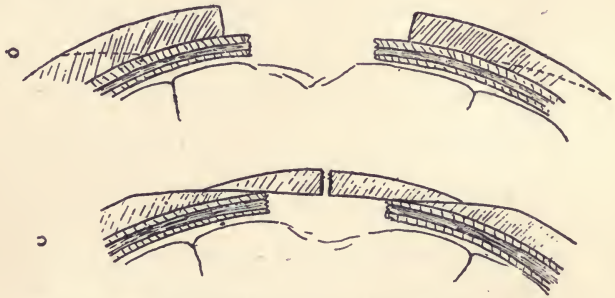


FIG. 53.—The bevelled flap method of closing defect in the scalp. (Cuthbert Wallace.)

Tangential Wounds of the Gutter Type.—These are best treated by excision of the scalp wound and removal of bone fragments, according to the extent of the injury.

When the dura is intact it should not be incised, even in the absence of visible pulsation; the risks of causing intradural infection by so doing are very considerable. When the dura is torn the indriven fragments can generally be removed easily, as they lie superficially. In this type of case it is especially important to cover over the lacerated brain area with scalp tissue, avoiding drainage unless absolutely necessary.

Through-and-Through Wounds.—These are probably best treated by excising and cleaning the entrance and exit wounds,

and carefully watching for signs of compression. If such signs appear, trephining ought to be carried out over the wound of entrance should it be possible to determine which it is. Excision of the scalp over the exit wound is sufficient.

Wounds of the Large Sinuses.—Operations upon fractures presumably involving these should be undertaken with the greatest caution. Trepanation should be carried out by the *en bloc* method. Should severe haemorrhage occur, it should be treated by the application of a muscle graft. A piece of muscle or fascia excised from the outer side of the thigh, held by an assistant over the bleeding vessel with the intervention of a smooth rubber dam, for a very short time, will control any haemorrhage from the brain or its membranes. Plugging of the sinus should not be attempted as it is liable to be followed by disaster.

Holmes and Sargent are of opinion that many cases of wounds of the sinus are better left alone.

Post-Operative Attention.—*Dressings.*—The after dressings are of the utmost importance, great gentleness and scrupulous cleanliness being necessary. If the wound is closed and aseptic, a dry sterile dressing is suitable. Should the wound be open and infected, irrigation with eusol or Dakin's fluid by Carrel's method may be tried. An oily preparation of Di-chloramin T. is very efficacious, and glycerine instilled into the wound and tubes is often used with success.

Drugs.—The patient should be kept quiet for forty-eight hours after operation, and suitable doses of morphia may require to be given.

Urotropin, from its antiseptic action in the cerebro-spinal fluid, is said to be of value. It is given in doses of 10 grains, four-hourly from the time of operation.

Distressing headache is sometimes present after operation; it may be controlled by aspirin and trional given together in 10-grain doses.

Lumbar Puncture.—Lumbar puncture is useful in relieving intracranial pressure. It may be used in the concussion stage and later. When the dura mater is intact the proceeding is safe, but when the membranes are torn considerable care must be exercised. In the latter case the sudden withdrawal of a large quantity of fluid may allow the brain to fall away from the surface, thus tearing down salutary adhesions which have formed between the pia-arachnoid and the dura mater.

Under such conditions no more than 2 to 6 drachms should be removed at a time.

Lumbar puncture is recommended for the reduction of a cerebral hernia, and also for the relief of symptoms of meningitis. It may be employed as a diagnostic aid, especially in the demonstration of meningitis.

Lumbar puncture has largely taken the place of contra-lateral decompression.

The Evacuation of Men suffering from Head Injuries.—When a case has been submitted to operation he should be left undisturbed for at least two weeks. If transport by barge is available this method should be chosen in preference to any other.

In certain cases arrangements have been made for the establishment of centres reserved for the reception and treatment of head injuries. These centres are generally situated in the rear of an army area. The cases are admitted directly from the Field Ambulance or Advanced Clearing Station, and they are retained in the centre for many weeks. This system has given great satisfaction, and it does not entail any real delay in operation.

CHAPTER XI

INJURIES TO THE SPINE

Gunshot wounds in the region of the spine affect the spinal cord in a variety of ways. The cord may be directly injured by the missile, fragments of bone driven inwards from the spinal column may lacerate it or compress it, or it may be seriously injured by the concussion effect of a high velocity projectile which has passed in proximity to the cord yet without directly touching it.

Complete and Incomplete Lesions.—The resulting lesions of the spine may be said to be complete or incomplete. Complete gunshot lesions are due to a direct hit upon the theca with penetration of the cord, either by the missile itself or by a portion of indriven bone.

In incomplete lesions, on the other hand, the missile hits the spinal column, and the resulting damage is the effect of concussion, of pressure, or of an indriven fragment.

Nature of the Lesions in the Spinal Cord.—The lesions found depend upon the site and the severity of the injury. The cord may be entirely divided with accompanying haemorrhage, intraspinal, subdural, or intramedullary—a complete spinal division. Laceration of the cord with incomplete division is uncommon.

In many cases the cord to outward appearances seems intact yet there are extensive medullary changes. There are small scattered haemorrhages especially in the grey matter, occasion-

ally a single large haemorrhage. There is frequently an oedematous swelling of the whole cord with areas of softening in the centre.

The condition of the spinal column varies from extensive comminuted fracture to simple perforation of the body or other portion of the vertebra without any extensive fracture.

The Symptoms of Spinal Injury.—The outstanding features are naturally paralytic in nature and these are discussed later. Apart from paralytic symptoms pain may be present. When it occurs it is a most distressing feature, and it forms an indication for immediate treatment. The pain may be of the "girdle type" with a distribution immediately above the level of the injury, or it may be of the "root type." Holmes believes that in many cases the pain complained of is "cord" pain rather than root pain.

Paralytic Symptoms.—*Complete Lesions.*—Such cases show a complete interruption in the tracts of the cord. It is evidenced by complete motor and sensory paralysis below the level of the lesion, a loss of reflexes, and a loss of sphincter control.

Incomplete Lesions.—There is always some degree of resulting paraplegia.

1. It may be flaccid, apparently complete, and yet be transitory.

2. There may be a transitory period of flaccid complete paralysis which merges rapidly into a spastic paralysis of varying degree and distribution.

3. Paralysis of a flaccid type may come on after an interval.

In early cases it is often very difficult to determine the degree of injury sustained by the spinal cord. The loss of power is at first almost invariably complete, and even in slight cases the knee-jerks are often absent for days.

Misjudgment of these signs might lead one to diagnose a complete lesion of the cord while as a matter of fact the signs are only temporary.

In the examination of early cases the greatest importance should be attached to the condition of tone in the muscles of the lower limb and the reflexes which are obtained from the stimulation of the soles of the feet. In severe cases attempts to elicit the sole reflexes produce no response. In less severe cases a slight response may be obtained in the shape of flexion of the toes and an associated flexion of the ham-strings. In cases which are still more favourable, stimulation elicits a withdrawal reflex of the limbs and Babinski's sign.

The Clinical Examination. — As far as is possible such cases should be submitted to an examination to reveal the probable level of the lesion in the spinal cord. Motor and sensory functions, reflexes, vasomotor and trophic changes are noted accurately. Attention must be paid to the condition of the bladder.

The Diagnosis of Spinal Injuries. — It is important to distinguish an organic paraplegia from a functional or hysterical paralysis. The latter is commonly observed in men who have been buried by shell-fire. The most important points in the differential diagnosis are :

1. In functional paraplegia sphincter control is not affected, while in organic paraplegia retention of urine is invariably present.

2. In functional paraplegia the tone of the muscles is increased ; in organic lesions the muscles are flaccid.

3. Knee and ankle reflexes are usually exaggerated in functional paraplegia ; in organic paraplegia they are abolished.

4. Babinski's sign is evidence of an organic lesion.

5. Functional paraplegia is often accompanied by irregular sensory changes which cannot be explained on any anatomical basis.

The Prognosis of Spinal Injuries.—The higher the situation of the lesion, the graver does the prognosis become.

A persistent, complete, flaccid paralysis, motor, sensory, and

reflex, is exceedingly grave as it indicates a complete physiological interruption of cord conduction.

In spastic paralysis the prognosis is favourable if the sphincters are not involved.

There are cases of apparent flaccid paralysis the result of concussion which eventually make a complete recovery, and in view of this statement it is generally unwise to give any prognosis until the case has been under observation for some time.

The Treatment of Spinal Injuries. — The treatment of spinal wounds is extremely disappointing. Operation is only rarely successful, and it should be undertaken only in these cases which show on X-ray examination a missile lying in the spinal cord or an indriven fragment which is pressing upon the cord. Even in cases which at first appeared promising the results have not been satisfactory.

Indications for Operation. — *General Considerations.* — Generally speaking, wounds of the spinal column and cord are comparable to head wounds in so far as surgical interference, except in a few instances, cannot hope directly to restore function.

The aim of any surgical treatment ought to be to eliminate as far as possible the dangers of sepsis.

It is often impossible to say in the early stages how much recovery can be expected, or, on the other hand, how permanent the disability is likely to be.

From these general considerations it would therefore appear that the treatment in the Casualty Clearing Station must be governed more by the nature of the wound than by the nervous symptoms.

Local Considerations.—The indications for operation on spinal wounds in the Casualty Clearing Station may therefore be summarised as follows:

(1) For the cleansing of ragged shell wounds, especially when the foreign body is retained.

(2) For the relief of the intense pain which is sometimes present.

(3) When X-ray examination shows indriven bone pressing on the spinal cord.

(4) When X-ray examination has accurately localised a foreign body within the bony or thecal canal.

Should the Clearing Station be working at high pressure it may be impossible to apply indications 3 and 4.

Contra-indications to Operation. — In concussion cases in which the cord is not injured directly by the missile or by fractured bone, operation can do no possible good.

Persistent flaccid paralysis also places the case beyond scope of operation except perhaps for the relief of girdle pain.

The Time for Operation. — Assuming that the indications for operation are limited to the relief of girdle pain and relief of pressure from the missile or from indriven bone fragments, the operation can scarcely be undertaken too early. Until recently the operation of laminectomy was very rarely performed in the Casualty Clearing Station, but if the conditions are favourable, and the patient can be kept for some time after operation, there are obvious advantages in performing decompression as early as possible.

Operative Technique.—With the patient lying on his face and the affected portion of the spine made prominent by a pillow or sandbag placed in front, or curled up on his side and a little on his face, a long vertical incision is made in the mid-line, the centre of the incision being over the affected portion of spine. Both sides of the spinous processes are freed from the muscles which lie laterally until there is a deep groove on each side at the base of each of which there lie the laminae. Bleeding at this stage can be controlled by packing dry gauze firmly into the grooves and leaving this in position for a few minutes. Should any large vessels continue to bleed, they may be secured by forceps. At this stage,

additional room may be obtained by dividing the spinous processes which have been exposed. This is done with strong bone-cutting forceps, each spine being bitten through at its base and removed. The laminae which it is proposed to remove are fully exposed, and they are cleaned accurately with a raspatory or chisel. The bony arches are now divided. For the purpose a Horsley's saw is applied to the outer side of the centre of the lamina and the cut is carried downwards and inwards until the laminae are almost completely divided or until the lack of resistance shows that the spinal canal has been entered. It is important that the cut should not be made vertically or the spinal canal will be missed altogether.

Having made the preliminary saw cuts, the bone-cutting forceps are applied to each lamina in turn and their division completed. It is seldom necessary to divide more than two. The section of the laminae does not at once allow their removal as they are still held by the strong ligamenta subflava ; they are levered up, however, with forceps, and the resisting ligaments cut through with strong scissors. With the removal of the laminae the spinal canal is fully laid open.

All effused blood is now removed, either by a hot douche or by careful swabbing. The exact nature of the injury is ascertained, small fragments of bone or foreign bodies are removed, and tears in the dura sought for.

It should be noticed whether the theca does or does not present its normal pulsation, colour, and tension. The anterior part of the spinal cord is examined, and to do this the theca is gently raised from one side by an aneurysm needle ; any loose or projecting piece of bone or foreign body lying here is removed. If the theca is undamaged it is unwise to incise it, as the dangers of a spreading infection are very real. In the event of the dura being already torn, the torn surface is gently washed with an antiseptic lotion and the tear is sutured with interrupted catgut or silk sutures.

Closure of the Wound.—The wound must be completely closed without drainage. The erector spinae of both sides are approximated by catgut sutures. The superficial muscles are closed in a separate layer and the skin edges are approximated. It must be remembered of course that in many cases an atypical operation is sufficient.

After-treatment.—In cases of prolonged operation there may be a considerable amount of shock, and this will require appropriate treatment. Pain is often severe and the free administration of morphia may be necessary. To lessen the possibility of the escape of cerebro-spinal fluid the head should be kept low and the foot of the bed raised. Sometimes there is persistent post-operative vomiting; bromide of potassium in doses of 10 to 15 grains has been recommended to control it.

Details of nursing will be governed by the general conditions as regards paralysis, bed-sores, and affections of the bladder and rectum, while in some cases pulmonary complications, hyperexia, and the like may have to be dealt with; but apart from troubles which are common to other cases of paraplegia, there are no essential difficulties in after-treatment.

The Treatment of Complications.—The most common cause of fatal termination in spinal injuries is cystitis with a subsequent septic pyelonephritis. The greatest care, therefore, is necessary in the passage of the catheter, and urinary antiseptics should be administered to all patients from as early a stage as possible. Frequent irrigation of the bladder is important; it prevents the development of cystitis and counteracts infection when such has developed. Solutions that may be used for washing the bladder are potassium permanganate 1 in 5000 or 10,000, oxycyanide of mercury 1 in 1000 or 5000, biniodide of mercury 1 in 10,000 or 20,000, tincture of iodine $\frac{1}{2}$ to 1 drachm to the pint, nitrate of silver 1 in 10,000 or 20,000, peroxide of hydrogen 1 in 10 or 1 in 20 of the twenty volumes, lysol $\frac{1}{2}$ to 1 per cent, protargol $\frac{1}{2}$

per cent or a solution of sulphate of quinine 1 to 2 grammes to the ounce. Several pints of the solution should be used, and the mechanical action of free washing with large volumes of fluid plays an important part.

The method of suprapubic drainage presents advantages over catheterisation or irrigation. The method employed must be one which prevents leakage around the suprapubic tube. One such method which has proved satisfactory is as follows: On account of the loss of sensation no anaesthetic may be necessary: if such is required a local anaesthetic is sufficient.

Fig. 54.—Pezzer's self-retaining suprapubic tube.

A 2-inch suprapubic median incision is made and the anterior bladder wall is exposed; the bladder has previously been distended with about 8 ounces of warm boracic lotion. With an ordinary sinus forceps held closed, a stab is made through the bladder wall and the blades are separated just sufficiently to permit the introduction of a Guyen or Pezzer self-retaining suprapubic tube, stretched on a long probe. This is facilitated by the previous introduction of a stay suture of catgut on each side of the area in which the bladder is opened. These sutures may be removed when the tube is in position, or they may be tied together round the tube. If the wound in the bladder is properly made, it will be found that the tube is tightly gripped by the bladder wall and the junction is completely water-tight. The tube should be pulled out until its expanded end lies against the anterior wall of the bladder, and it is a point of great importance that the opening into the bladder be made at as high a level as possible. By a glass connection and rubber tubing the urine is conducted into a vessel lying to the side of the

bed. After this operation daily irrigation of the bladder with suitable fluid should be carried out. The injection is made from the external meatus along the urethra into the bladder and finds its exit by the suprapubic tube. If the tube becomes blocked it can be cleared by syringing through it into the bladder. The tube requires replacement every seven or ten days.

In connection with the suprapubic operation this warning must be given. If the operation is indifferently performed and the wound leaks the condition of the patient is endangered thereby, more especially if a previous laminectomy has been performed.

Sufficient details from home hospitals have not yet been obtained to say whether the suprapubic operation has diminished the death-rate from urinary troubles.

Dr. Head has made the observation that a patient with retention can nearly always produce an act of micturition if the inside of the thigh is lightly scratched; this holds good when the stimulated region is anaesthetic.

To elicit the reflex the bladder must be quite free from sepsis.

This is a most important observation, as in many cases it may negative the advisability of doing a suprapubic cystotomy.

The Evacuation of Spinal Injuries.—Cases of paraplegia which have not been submitted to operation should be evacuated to the base as early as possible. Water-beds, air-cushions, and various nursing facilities are more accessible at the base hospital than in a Casualty Clearing Station.

Those cases which have been operated upon should be retained for at least a fortnight. Of all possible means of evacuation that by barge is the most suitable. Before any spinal case is evacuated it is most essential to see that the bladder has been emptied.

CHAPTER XII

LESIONS OF THE PERIPHERAL NERVES

LESIONS of the peripheral nerves are very liable to be overlooked. The reason of this is twofold: their injury may produce no obvious symptoms complained of by the patient, and in many cases such injuries are overshadowed by more serious wounds.

It is therefore most essential that the surgeon should be on the watch for nerve injuries, and it is very desirable that whenever nerves are found to be divided they should be carefully sutured when this is possible. Only in a very small proportion of cases will this primary nerve suture be successful, but even if the suture should not hold permanently the temporary fixation of the divided ends has great advantages. It prevents retraction, it maintains the portions of the nerves in the same plane, and both of these are factors which greatly facilitate subsequent operations.

It is not our intention to enter into any detail on the question of nerve suture, but there are one or two points to which attention may be drawn.

It will be judged from the anatomical position of the wound and from the symptoms which are present whether or not the nerves are damaged.

If there is certainty or if there is any suspicion that damage has occurred, the injured nerve is exposed.

It is freed for about a couple of inches above and below the

point of damage. If section has been complete, the damaged ends are divided with a sharp knife about $\frac{1}{4}$ inch from the extremity; healthy nerve may be recognised by the protrusion of nerve bundles. On no account should nerve section be made with scissors which causes crushing of the fibrils.

The amount of shortage in the nerve can now be gauged and steps taken to make this good, so that end-to-end suture can be accomplished. The shortage can be overcome in four ways:

(1) By flexion of intermediate joints.

(2) By free dissection of the nerves for a considerable distance above and below the lesion.

(3) By translation of the nerve path to a straight line.

(4) By dislocation of the nerve.

The first and second only are applicable to nerves of the lower extremity, the third is applicable to the ulnar and musculo-spiral, and the fourth is referable only to the ulnar at the elbow-joint.

The nerve must not be unduly pulled upon, although a certain amount of gentle traction is permissible if necessary, as there is little doubt that the sheath is shorter than the nerve fibres. A temporary stitch of fine catgut is placed through the nerve ends with a fine non-cutting needle at a distance of about $\frac{1}{2}$ inch from each extremity. The nerve is sutured by means of the finest domestic sewing needle and the finest sewing silk or linen thread obtainable. A continuous stitch is put round the nerve involving nothing but its sheath. If possible eversion of the sheath edges should be brought about. The catgut stay suture is removed and the whole suture line examined. A sleeve of fascia taken from the thigh may be used to envelop the suture line. Every divided nerve should be sutured with the greatest possible care. So many wounds are now being closed by primary suture after excision that primary suture of nerves offers a very fair chance of giving good results.

After nerve suture every effort should be made to close the wound and to obtain primary union, or, if this should prove impossible, to bury the nerve by the readjustment of muscle and fascia.

Throughout the operation the nerve should be treated with all possible gentleness. It must never be twisted, torn, or unduly separated from its bed. It is wiser to dissect structures from the nerve rather than to dissect the nerve from its surroundings. It must not be stripped bare for too long a distance or it may become devascularised.

The subsequent dressing is so applied that there is the least possible strain upon the line of suture, and the part is so splinted that the affected muscles are maintained in a relaxed position.

In a work of this kind, we are not concerned with the careful after-treatment which these cases require, but as early as possible the patient is evacuated to some Base Hospital where special facilities for after-treatment are arranged. We need hardly draw attention to the importance of forwarding with these patients the most careful note of any operative procedure which may have been carried out, and also of the clinical condition before operation.

CHAPTER XIII

HAEMORRHAGE AND WOUNDS OF THE BLOOD-VESSELS

The Treatment of Haemorrhage at the Front.—The principles of the treatment of haemorrhage are well established, and these principles lay down as an essential rule that bleeding is to be arrested by pressure upon or ligature of the bleeding-point itself and not by constriction of the limb above or by tying the artery on the proximal side of the injury.

The systematic use of the elastic tourniquet should be limited, and its use, apart from during an operation, should be restricted to those cases in which a limb is completely smashed or blown away, or as a temporary measure while a patient is being carried to a regimental aid post.

If the medical officer finds that a tourniquet has been already applied, it is his duty to remove it at once and to examine the limb so as to ascertain whether there is actually any haemorrhage, and, if so, to take measures for its arrest.

The application of a tourniquet, if it is to be efficient, causes intense pain; even if applied for an hour it seriously damages the nutrition of the tissues, and if left in position for six hours the affected limb will certainly die.

At the field ambulance it is the duty of the medical officer to examine the wound and see if any definite bleeding-point requires to be tied. If from the position of the wound or the surroundings of the patient ligature is difficult, forceps should be applied and left *in situ*.

Should examination show that there is no obvious vessel to be tied, direct pressure by plugging will usually stop the haemorrhage. It is essential to see exactly where the bleeding is proceeding from, and the first part of the plug is placed as near as possible on the bleeding spot. The whole wound is then packed with the plug and the limb firmly bandaged upwards from the hand or foot as the case may be. In order to avoid constricting the limb and yet to secure sufficient pressure on the part, the bandage should always be applied over a wooden splint of sufficient breadth placed on the opposite side of the limb.

In cases in which the haemorrhage has been at all severe, a note should always be made of the fact on the field medical card, and the case should always be marked URGENT in large capital letters. When such a case is evacuated to the Casualty Clearing Station it is advisable to leave a loose tourniquet on the limb, the orderly in charge being instructed to draw the ends tight if any severe bleeding occurs. When a tourniquet is applied to an avulsed limb it should be placed as low down as possible: this means a saving in the length of limb when amputation is done.

At the Casualty Clearing Station all cases of suspected haemorrhage must be thoroughly investigated under an anaesthetic. The smaller bleeding-points are tied, and wounds of the larger vessels are dealt with as will be described.

Recurrent Haemorrhage.—The directions given for the treatment of primary haemorrhage are equally applicable to the recurrent variety.

Secondary Haemorrhage. — The improvement which has resulted in the technique of treatment of wounds has materially lessened the occurrence of secondary haemorrhage. Nevertheless, this complication remains as one of the most serious and difficult problems which one has to face. It is the result, of course, of an extending septic infection in the wound. Except

in the case of wounds of the jaw and face the complication is uncommon during the first week, and it is during the third week after infliction of the wound that the haemorrhage is most common.

Makins has pointed out that the practice of cutting the vessel short in an amputation so that it lies in a pocket instead of on the face of the stump may be a cause of secondary haemorrhage.

The best prevention of secondary haemorrhage is to make every effort to get wounds into such a condition of sterility that early secondary suture can be performed.

When haemorrhage occurs, a tourniquet should be applied and the bleeding-point sought for in the wound: when found it is treated by ligature of both ends of the bleeding vessel.

Ligature of the main artery in continuity should not be done, as disaster is likely to follow either from gangrene or from recurrence of the haemorrhage. If a tourniquet cannot be applied as in the case of bleeding from wounds of the head and neck, or from the axillary or subclavian vessels, it is justifiable to place a temporary ligature or clamp on the main artery while the bleeding-points are being sought for and secured.

The clamp or ligature should be so applied that while it arrests the blood flow, it does not injure the inner coat of the vessel.

If the position of the bleeding-point is such that a ligature cannot be employed, pressure forceps should be applied and left in position for at least forty-eight hours.

It is possible that neither ligature nor forcipressure is feasible, in which case it may be necessary to resort to the objectionable method of plugging. If the bleeding has been severe the plug should be left in position for a period of at least forty-eight hours.

If these various methods fail to arrest the bleeding and it becomes essential to ligature the vessel in its continuity, the

most distal point of the vessel which will control the haemorrhage should be selected for the application, but the vessel should be exposed for some distance in order to ensure that the ligature is placed upon healthy vessel wall. The resulting wound should be left open.

When all other means have been exhausted and the general condition of the patient justifies the risk, a recurrence of secondary haemorrhage in the extremities should be treated when practicable by removal of the limb.

Later Treatment.—The general lines of treatment after primary or secondary haemorrhage consist in rest, measures for the counteraction of co-existing shock, the administration of an alkali to counteract the acidosis which invariably results from severe haemorrhage, and the exhibition of one of the various infusions to replace the lost fluid and to maintain the blood pressure (see chapters on Shock and Transfusions).

Wounds of the Large Blood-Vessels.

Isolated lesions of the blood-vessels are not particularly common. In the days when the dome- or ogival-shaped bullet was employed, they were frequently met with, but since the sharp-pointed bullet has come into use its instability results in such extensive lesions that damage localised to the blood-vessels is exceptional.

When very small fragments of bone or shell are the injuring missiles, isolated vascular lesions are somewhat more common.

Pathological Considerations.— *Contusions of the Vessel Walls.*—The missile may fail to perforate the vessel wall and yet it passes in such proximity to it that the vessel wall is contused or a portion of the outer coat is actually torn away. In other cases, while the vessel from its exterior seems unaltered, the inner and even the muscular coat are ruptured.

As a result of the contusion of the vessel wall, intravascular thrombosis is liable to occur. At first it is local and incomplete, eventually it may become complete and extensive, especially if the surrounding parts are infected.

Secondary haemorrhage may occur from these incomplete lesions, and aneurysms may occur as early or as late complications.

A contusion of the vessel wall, if thrombosis has occurred, may result in gangrene of the limb concerned: thrombosis is more common in veins than in arteries.

Perforating Wounds of the Blood-Vessels.—In the recent state the wound in the vessel is contused, the edges being tattered and irregular; as repair develops the edges become smooth and rounded (Makins).

The extent of the damage varies: there may be complete severance of the vessel; there may be a wound involving the greater part of the circumference; or there may be a perforation of one or both sides of the vessel's walls.

Changes subsequent to Wound.—*Primary Haemorrhage.*—As a result of the wound in the vessel there is an immediate primary haemorrhage. The almost invariable history given by the wounded man is one of a primary spurt of blood, often abundant, but readily controlled by local pressure and the application of a dressing. It is a most important fact to bear in mind that in large open wounds, vessels of the calibre of the brachial or femoral arteries are frequently met with completely divided yet occluded by a firm efficient thrombus.

Perivascular Haematoma.—Apart from the external haemorrhage, the most common sequence of a gunshot wound of a large vessel is the development of a perivascular haematoma. There is a pulsating collection of blood in the surrounding tissues, its line of extension being dependent on the anatomical arrangement of the part concerned. The most characteristic are those which develop in connection with comparatively

superficial vessels, such as the common femoral or the third part of the subclavian. In these there is widespread ecchymosis of the overlying skin. When the deeper vessels are wounded ecchymosis is rare and the local soft fluctuating swelling is replaced by a tense general swelling of the limb.

The effused blood now undergoes coagulation and this begins at the circumferential part of the effusion: thus any further extension of the extravasation is prevented. As the coagulation progresses, shrinkage of the resulting clot takes place, and there results a definitely localised pulsating swelling which may actually project on the surface. The extent of the coagulation varies: the central portion of the effusion may remain fluid and in direct continuity with the contents of the wounded vessel; in other cases the entire effusion may become converted into a firm clot.

False Aneurysms.—The impact of the blood-stream opposite the defect in the arterial wall tends to open out a rounded space in the recently coagulated blood or to enlarge any residual space remaining in the clot. The resulting cavity acquires a boundary formed by the deposition of well-marked layers of laminated clot, and when this stage is reached the term false aneurysm is applied to it.

Behaviour of the Surrounding Tissues.—The presence of the blood clot appears to stimulate reactionary changes in the surrounding tissues. The connective tissues of the vascular cleft, the intermuscular spaces, and the muscles themselves become infiltrated with serum and an abundance of leucocytes destined to take part in the subsequent absorption of the clot. The organisation of this effusion surrounds the vessels and the related clot with a mass of tissue like firm bacon. It is important to remember this fact when any idea of later operation is being entertained.

Clinical Features.—There are the general features which are common to severe haemorrhage. Locally there are the obvious

signs of haemorrhagic effusion, of a perivascular haematoma, or of a false aneurysm.

A characteristic arterial bruit may be present. It indicates an incomplete solution of continuity of the vessel wall. The murmur is most noticeable in the first few days; it is conducted for a considerable distance peripherally along the vessel, and its character depends upon the position and shape of the vessel wound and the degree of irregularity of the margins. The complete coagulation of the effused blood causes a cessation of the bruit. In the early period the heart is dilated and the cardiac action is tumultuous.

Progress and Complications.—The typical course of a perivascular haematoma is one leading to contraction and localisation, a definite false aneurysm being the commonest final result. In the most favourable cases the aneurysm itself consolidates spontaneously, and a cure by natural processes results.

Complications.—These may be divided into two groups accordingly as they appear early or late in the progress of the case.

The early complications include oedema, pain from nerve pressure, and gangrene of the limb as the result of pressure exerted on the collateral circulation of the limb.

Secondary haemorrhage, embolism, and secondary inflammatory infection are the other common early complications.

The later complications need not be considered in a work of this description; they include more especially arteriovenous aneurysm and aneurysmal varix.

Treatment.—In dealing with a wound of the blood-vessels one has a certain choice of procedure, but there is one rule which should be continually kept in view. It is this: if possible, delay any procedure which involves tying the main vessel in its continuity until the collateral circulation has had an opportunity of developing. Ligature of the main vessel

before the collateral circulation has come into play will almost certainly result in gangrene of the limb affected.

The various possible operative procedures are as follows:

(*a*) Suture of the vessel—arteriorrhaphy.

(*b*) Artificial canalisation (Tuffier's tubes).

(*c*) Ligature.

(*a*) *Suture of the Vessel—Arteriorrhaphy.*—This procedure may be adopted in partial wounds of the vessel wall and in cases of complete division in which end-to-end anastomosis is possible.

The operation is contra-indicated when there is such extensive destruction of the vessel as to prevent approximation of the ends.

Technique.—The vessel is exposed for a distance of an inch or more on each side of the wound, and the circulation is commanded by applying artery clamps (Crile's) the blades of which are protected with rubber, or by passing a loop of tape round the vessel and pulling the vessel against one's finger. Only the right amount of pressure required to arrest the circulation should be exerted. When the circulation is thus commanded, the wound is sutured with the finest spring-eyed round intestinal needle bearing the finest silk or celluloid thread obtainable. Both needle and silk have been impregnated with liquid paraffin or boiled in sterile vaseline oil. Of all the possible methods of suture Dorrance's is undoubtedly the best. Briefly it is as follows: When suturing a longitudinal wound, the thread is first entered about an eighth of an inch from one end of the wound, made to penetrate only the outer and middle coats, brought out again and tied, the free end being left long. The needle is now made to penetrate all the coats of the vessel from without inwards on one side of the wound and as near the edge as possible; it is then carried through the walls of the vessel on the opposite side of the wound from within outwards. It then re-enters the arterial

wall from without inwards, passing across the incision, and penetrates the opposite side from within outwards, thus making a mattress stitch. This suture is continued throughout the length of the wound; at every third loop the suture is carried back a stitch's breadth, in order to maintain the steadiness of the approximation. On emerging at the other end of the wound, the thread is passed through the two outer coats of the vessel an eighth of an inch from the end of the incision, and is then tied in a single knot.

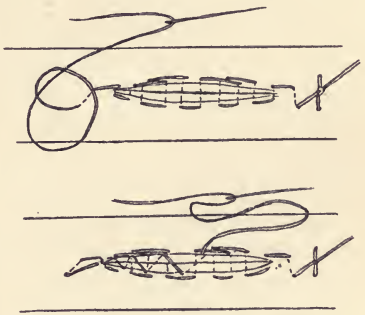


FIG. 55.—Dorrance's arteriorrhaphy suture.

The continuous mattress suture thus formed is reinforced by a second continuous running stitch taking up the edges of the incision between the loops of the mattress suture; when this reaches the point at which the original suture commenced, the two ends are tied together and the suture is complete.

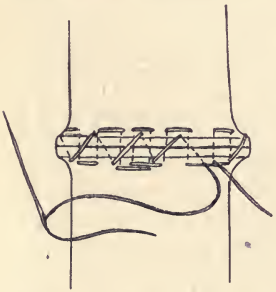


FIG. 56.—Dorrance's suture in end-to-end anastomosis.

This method of suture approximates the intima on the two sides, and at the same time buries the suture deeply, so that it is out of the blood-stream, and little if any coagulation occurs at the site of union. After the suture has been completed, the clamps are removed first from the distal and then from the proximal end; and after having ascertained that the wound is blood-tight, it is a good plan to surround the artery by the deep

fascia which is sutured over it so as to make a loose cellular envelope.

When end-to-end suture has to be made the procedure is practically similar. The divided ends of the vessel are cut through with a sharp knife so as to expose healthy wall.

Three or four temporary stay sutures are inserted so as to bring the opposing ends into correct apposition. A circular mattress stitch is then inserted.

(*b*) *Artificial Canalisation* (*Tuffier's Tubes*). — In such vessels as the common carotid, the femoral, and the popliteal, when the degree of injury is so extensive as to make suture impossible, and when immediate ligature often leads to acute local anaemia and gangrene, Tuffier's tubes may be tried to maintain the current of the blood-stream pending the increase in the collateral circulation.

The tubes are made of glass or silver in various sizes ; having been previously coated inside with hard paraffin they are kept stored in absolute alcohol.

The damaged vessel is exposed and controlling clamps are applied. The damaged ends of the vessel are excised, and a loose purse-string suture is run round each about an eighth of an inch from the end. The tube is inserted into the open ends of the vessel and the purse-string sutures are tied. The tube and the vessel are temporarily buried by suturing the soft tissues over the area. Sooner or later clotting occurs in the tube ; it may occur within a few hours, or it may not take place for several days. When a collateral circulation has been definitely established the wound is opened up, the vessel ligatured above and below the damaged area, and the tube removed.

(*c*) *Ligature.*—In most cases of arterial injury in which interference is necessary, the operation will consist of ligature of the vessel. Simultaneous ligature of the vein as well as of the artery does not increase the risk of gangrene. On the

contrary, there is good evidence that the risk is actually lessened by tying the main vein (Makins).

Treatment of Peri-vascular Haematomata and False Aneurysms.—The primary treatment of peri-vascular haematomata should be rest and an expectant attitude.

Early operation is necessitated under the following circumstances: (1) secondary haemorrhage; (2) continuous increase in size; (3) secondary diffusion; (4) developing gangrene from pressure on the collateral circulation; (5) when suppuration threatens.

When operation becomes necessary, should suture or Tuffier's tubes be impracticable, a ligature should be placed on each side of the wound in the vessel, care being taken to close also any branch which may arise opposite the injury. When early operation is required, a tourniquet is always to be employed if practicable.

The large majority of the haematomata eventually become false aneurysms, and for this condition also an expectant attitude is the best for some weeks.

CHAPTER XIV

GAS GANGRENE

Gas gangrene has been a common and an extremely serious complication of infected war wounds. When the present war began our knowledge of the subject was extremely limited: it had been noted by various writers as occurring in previous campaigns and on rare occasions, it was met with in civil practice, but we possessed very little trustworthy information regarding the pathology of the condition.

Pathological Considerations.—*The Organisms concerned.*—Gas gangrene arises by the infection of the wound with anaerobic organisms which are probably faecal in origin. These organisms are extremely numerous in highly fertilised areas and long-cultivated soil. They may be divided into two groups:

(*a*) A Saccharolytic group, which decomposes carbohydrates with the production of acids, of carbon dioxide and hydrogen gas, and which in the early stages has very limited effects as a proteid splitter.

(*b*) A Proteolytic group which vigorously digests protein, producing ammonia bodies, and has very feeble powers in the decomposition of sugars.

It is probable that the disease is mostly caused by five organisms, though the part they play and the frequency with which they appear are by no means constant.

The individual organisms may be grouped as follows:—

Saccharolytic group:

1. Bacillus Welchii.
2. Vibrion septique.
3. Bacillus oedematicus.

Proteolytic group:

4. Bacillus sporogenes.
5. Bacillus histolyticus.

Each of the first three is able to flourish in the body by itself and to cause death. The fourth is not usually pathogenic by itself either in man or animals. The fifth causes death in animals, but the rôle which it plays in the human subject is not accurately known.

By far the most frequent agent is the Bacillus Welchii, and it is often aided by the Bacillus sporogenes.

The part played in man by the Vibrion septique and by the Bacillus oedematicus is still the subject of inquiry, but it seems probable that the Vibrion septique is a causal agent in some acute (fulminating variety) and fatal cases.

Effects of various Organisms.—From a study of the disease in man and of experiments in animals the following would appear to be the naked-eye changes produced by the infecting agents:—

1. Bacillus Welchii:
   - (*a*) Yellow oedema, sometimes blood-stained.
   - (*b*) Much gas production.
   - (*c*) Dull dirty brick-red colour of muscles.
   - (*d*) Soft pulpy muscles.
   - (*e*) Slight sourish smell.
2. Vibrion septique:
   - (*a*) Blood-stained oedema.
   - (*b*) Considerable gas production.
   - (*c*) Deep red colour of the affected muscles.
   - (*d*) An odour which is not putrid but rather rancid in character.

3. Bacillus oedematicus:
   (*a*) Colourless gelatinous oedema.
   (*b*) Small amount of gas production.
   (*c*) Pale pink colour of muscles.

4. Bacillus sporogenes:
   The appearances are somewhat similar to those produced by the Bacillus Welchii, with which this organism is associated. There are two distinctive features: (*a*) olive-green colour of muscles, the colour afterwards turning to black; (*b*) a putrid odour.

5. Bacillus histolyticus:
   The muscles and fasciae disintegrate with extreme rapidity, and the muscles acquire a dirty brownish-red appearance.

The Sequence of Events after Infection with Bacillus Welchii and sporogenes.—To secure the efficient development of the organisms they require to be implanted in dead tissue, and this unfortunately is too often ensured by the modern type of wound. The projectile which carries in the infection also devitalises the tissues to such an extent as to facilitate the further development of the organisms. When the infection is once established in a nidus within the body the developing organisms under suitable conditions produce a further death of the tissues, and thus the process spreads from the point of original implantation. As stated above, one of the most common combinations is that of Bacillus Welchii and sporogenes. The latter, though toxic in itself, appears to favour the growth of the former in the following manner:—

The Bacillus Welchii after a latent period produces gas and acid as a result of its action on the muscle sugar. Coincidently, the Bacillus sporogenes begins to exert its proteolytic action and ammonia bodies are produced, thus neutralising the excess of acid which otherwise would have

proved inimical to the further growth of the Bacillus Welchii. At this stage of the infection the Bacillus Welchii begins also to exert its proteolytic action. The acid produced by this last-named bacillus turns muscle red, and at a later stage the sulphuretted hydrogen set free by protein digestion, combining with the iron in the haemoglobin, converts the red colour into black. Once the process of infection has been established, the death of the surrounding tissues caused by the toxine produces the environment necessary for a progressive development of the condition.

Related Factors in the Infection.—The infection of a wound with the causative bacilli does not necessarily result in the development of gas gangrene. If gangrene should not appear, the organisms tend to die out, and they are replaced by pus-producing organisms. The infection, however, may be latent in a wound for a considerable period and eventually give rise to symptoms. The likelihood of the infection becoming established depends upon the heaviness of the infection, upon the degree of devitalisation of the tissues, and upon the retention in the wound of foreign bodies and portions of clothing.

The Tissues affected.—Primarily and most importantly, gas gangrene is a disease of muscle. It may extend into areolar tissue, especially if this is infiltrated with blood (retro-peritoneal infection). With the exception of the pleura, it is rarely met with in serous cavities, and if it should develop in these situations it proves readily amenable to efficient treatment.

Morbid Anatomy.—Muscles fall a victim to the disease in two ways:

(1) A muscle dies in consequence of a cutting off of blood-supply and undergoes a post-mortem infection.

The colour of the affected muscle will depend upon the stage of the infection—it may be the purple red of dead

muscle, it may be red or yellowish green or black and diffluent.

(2) A muscle (usually a wounded one) with an intact blood-supply is gradually invaded by the bacilli, which, starting from the wound, make their way towards the extremities of the muscle until it is totally destroyed.

In such a case the line of invasion can be seen and the different zones of infection recognised.

At the actual wound the muscle is black, friable, or diffluent. Next comes a zone in which the predominant colour is red. Separating the red zone from the healthy muscle is a yellow band, irregular in outline, somewhat raised above the surface and hard to the palpating finger.

There are many cases, however, in which it is impossible to distinguish such various zones of spread. In these a loss of contractility is the first thing to be observed, and when this has been established the muscle rapidly changes its colour through varying stages of dirty red and greenish yellow to a black diffluent mass.

Origin and Diffusion of the Gas.—Gas can be demonstrated in the muscle in the onset of the red stage. It can be seen, at first, as bubbles between the muscle fibres, afterwards it passes out under pressure into the areolar tissue, and hence through spaces in the fascia into the subcutaneous tissues. Having gained the subcutaneous area, it may spread widely in any direction.

The gas has a deleterious effect in so far as it exerts pressure within the fascial sheath of the limb, constricting the blood-vessels, and producing that amount of interference with the blood-supply which is so favourable to an extension of the infection.

Reaction of the Surrounding Tissues.—There is often a serous oedema of the areolar tissues around the affected muscles, and also of the overlying subcutaneous tissues. In

the early stages this effusion is sterile or only slightly infected, later it becomes heavily infected.

The colour of the effusion varies probably with the infecting agents. With the Bacillus Welchii the effusion is yellow, with the Vibrion septique it is blood-stained, with the Bacillus oedematicus it is colourless.

Clinical Features.—*Varieties of the Disease.*—Three types of the disease have been classified:

(*a*) *The "Group" Type*, when a muscle or group of muscles are attacked. Here a wounded living muscle may be invaded as above described, or a muscle or muscle group cut off from their blood-supply may become infected throughout their length.

(*b*) *The "Segmental" or "Massive" Type.*—Here it is almost always a question of post-mortem infection subsequent to the obstruction or division of the main artery of the limb.

(*c*) *The "Fulminating" Type.*—This is a purely clinical variety which starts originally either as (*a*) or (*b*). It is an extremely rapid and a highly fatal type. Possibly it is due to an infection other than that of the Bacillus Welchii.[1]

Symptoms.—The onset of the disease is exceedingly rapid, and within a few hours a man previously in good condition is found to be *in extremis*. There are certain common symptoms which should always arouse suspicion. They are pain in the limb, marked increase of pulse rate, a sudden rise of temperature, and vomiting. The suddenness of the onset points to the necessity for careful watching during the night, as it is at this time that the early symptoms escape recognition.

Physical Signs—(*a*) *The "Group" Type.*—The limb shows some degree of swelling—slight at first, but progressive. The

[1] Investigations by Weinberg and Ségum (*Compt. Rend. des Séances de l'Acad. des Sciences*, 1916, tome clxiii. p. 449), and Wolf and Harris (*Journal of Pathology and Bacteriology*, vol. xxii. No. 1, p. 1), indicate that the "Fulminating" type is due to the action of the Bacillus histolyticus.

overlying skin, at first normal in appearance, becomes tense and blanched, and as the swelling of the limb increases it presents a mottled appearance, and finally a greenish-yellow colour. One often notices a peculiar bronzing of the skin; it appears to be the result of a subcutaneous infection. It may disappear spontaneously, but often it is a precursor of a rapid destruction of the cutaneous surface. It is important to remember, however, that there may be advanced gangrene of the underlying muscles with little or no perceptible change in the overlying skin.

Early in the progress of the case, the area around the wound becomes tympanitic, crepitation can be elicited, and bubbles of gas escape from the wound.

In the early stages there is no discharge from the wound, but later a foul-smelling dark fluid escapes, and at a still later date the discharge becomes of an orange colour. The odour of the wound depends on the type of infecting organism and on the stage of infection. In the early stages a characteristic smell is absent, but later it becomes foul and acrid.

If muscle is exposed to view, it presents the colour changes we have already described.

(*b*) *The "Massive" Type.*—When this variety of the disease develops after the main artery of a limb has been occluded, it occurs in the segment of the limb distal to the one in which the blood-supply has been arrested, *i.e.* in the leg where the femoral artery has been cut or tied. It is really a post-mortem infection of a segment of a limb. To this there are added rapid swelling of the limb, crepitation, and the general symptoms which we have enumerated.

(*c*) *The "Fulminating" Type.*—This variety is distinguished by an extremely high mortality. In its beginning it resembles either the "group" or the "massive" type, but it extends with the most lightning-like rapidity. Surgical interference is often unavailing. Amputation may be performed through

what appears to be healthy tissue well above the limit of the disease, but within a few hours recrudescence of the disease appears and rapidly proves fatal.

Later Symptoms and Signs.—If the disease continues to progress, the various constitutional symptoms become aggravated: the pulse quickens, vomiting is incessant, the temperature falls and remains subnormal, the body surface acquires a faint jaundiced hue, the extremities are cold and blue. It is remarkable that the mental condition usually remains clear and acute until the end, though there may be confusion of mind, delirium, and restlessness.

Treatment.—In the early stages of the disease, efficient surgical measures offer a very favourable chance of recovery.

Prevention Treatment.—There are certain points common to the early treatment of all wounds which are important.

Any appliance which constricts the limb and so interferes with the blood-supply should be avoided (tourniquet, etc.).

Avoid anything of the nature of wound packs or of dressings which tend to retain wound secretions.

At the Casualty Clearing Station it is important to avoid any delay in complete mechanical cleansing of the wound, in thoroughly excising all devitalised or partially devitalised tissue, and in releasing any collection of extravasated blood.

Active Treatment.—The surgical treatment adopted is governed by two conditions: by the state of the patient and by the extent of the gangrene. It should be borne in mind that the lesion is not a horizontal one, but, owing to certain muscles being infected and others not, that the top level of the disease is very uneven, mounting much higher at one point than another.

The Treatment in the "Group" Type of Gangrene.—If the patient is in a good condition, the local treatment consists in thorough mechanical cleansing of the wound. The affected area is exposed by free incision. All muscle which has lost its

power of contraction, which does not bleed or which is altered in colour, is removed. This may necessitate a complete excision of a muscle from origin to insertion. The resulting wounds are left open and are treated by the Carrel-Dakin or other suitable method ; afterwards they are closed by delayed primary or by secondary suture.

If the general condition of the patient is bad—and this is most probably the case when there is some complicating factor such as a compound fracture of the bone—amputation is the procedure of choice. The level of the proposed amputation will depend on the condition of the muscles. This should be ascertained by the use of lateral incisions starting from below and working upwards. An extension of these incisions will be used to fashion the flaps.

The Treatment in the "Segmental" Type of Gangrene.—When the gangrene has become established, amputation is the only treatment.

The Treatment of the "Fulminating" Type.—This type is seen generally in a recurrence after amputation. There is really no treatment which is of any avail ; re-amputation sometimes offers a meagre chance of success.

Methods of Amputation.—If the amputation is being done at the thigh level, short flaps of some description should be made ; the wound is kept open for some days, and, if desired, it may be irrigated by the Carrel-Dakin method.

Below the knee, where amputation will almost always be of a provisional nature, the guillotine method is often the best. It may be performed through the head of the tibia or through the knee-joint.

The cut surface of the amputation stump should be carefully examined. The appearance on section of an individual muscle may afford evidence that it is infected, the disease having extended locally above the general level. If such be the case, the individual muscle should be dissected out. In

this way the disease is efficiently removed and length of limb is saved.

General Treatment.—The usual remedies for the treatment of shock are carried out. Stimulants are given freely with advantage. As all these cases are suffering from some degree of acidosis, it is important to administer an alkali. It may be given by mouth (Sodium Bicarbonate, 8 drachms to one pint of water), or if the general condition is poor and there is persistent vomiting, it may be given intravenously (4 per cent solution of Sodium Bicarbonate).

The serum treatment of the disease, both prophylactic and therapeutic, is under trial, and as yet no definite statement can be made as to its efficiency.

CHAPTER XV

AMPUTATIONS

Practically speaking, in the Casualty Clearing Station only primary amputations are performed; secondary amputations are reserved for a later period and are performed at the Base Hospital. Therefore primary amputations only will be considered here.

Conditions which necessitate Primary Amputation.—The varieties of conditions which require amputation may be classified as follows: (1) complete avulsion of the extremity; (2) multiple comminuted fractures with severe laceration of the soft tissues and involvement of the large joints; (3) severe compound fractures associated with irreparable injury to the main blood-vessels and nerves and extensive laceration of the soft tissues; (4) severe spreading infection of a limb (Gas Gangrene).

General Guiding Rules.—The main considerations are to save life and to save length of limb. To fulfil these conditions it may be necessary to forgo at this stage any attempt at fashioning good flaps, and in such cases it is left to the Base Hospital to perform a secondary amputation.

There are certain conditions under which it is inadvisable to attempt to fashion a permanent stump. These conditions are: (1) severe shock; (2) multiple wounds.

(1) *Shock Cases.*—It may be advisable simply to trim an

avulsed limb or to remove the limb at the site of fracture. In these cases, however, short flaps should generally be made and left open.

It has been stated that if a considerable degree of shock is present, amputation should be delayed until the intensity of the shock has diminished. Recent experience, however, shows that immediate amputation of a crushed limb is distinctly beneficial to the patient. The operation is followed by a lessening of the shock, and moreover it prevents the development of the toxaemia which follows severe crushing of muscles.

It is right to amputate under these conditions. Gas and oxygen is employed as the anaesthetic, and the blood-pressure is restored by intravenous injection of blood or gum.

(2) *Multiple Wounds of the Limb.*—It is not advisable to amputate through a segment of a limb which is covered with multiple wounds. Primary healing is unlikely to result, and consequently there is a loss of length of the limb with a resulting bad stump. For example, if the leg is shattered in its upper third, while the thigh is covered with multiple wounds, it is better to perform a provisional amputation below the knee-joint than to carry out a flap amputation through the thigh with all the attendant risks of muscle sepsis.

When the condition of the limb and of the patient permit, a primary amputation should be performed by one of the recognised methods practised in civilian surgery, suitable flaps being formed.

Drainage of the stump should nearly always be provided if only for the first twenty-four hours. If the part through which the amputation has to be done is already infected, free drainage should be secured by turning back the flaps, fixing them in this position by sutures for a few days, and leaving them open.

In deciding on the site of amputation, as much of the limb as possible must be saved; it is unwise to limit oneself to preconceived ideas of the "seat of election."

Amputation through joints is to be avoided as a rule, except as a life-saving measure or as a temporary expedient.

Methods of Amputation.—It is unnecessary to enter into the details of the possible methods of amputation; the variety of method will depend upon the local conditions. The following method, however, adopted as a routine whenever possible, has been found satisfactory. A circular skin incision is made and a cuff of skin is dissected back for 1½ to 2 inches. The muscle is then divided obliquely in such a way as to support the skin without producing too bulky a flap. The remainder of the muscle is divided circularly down to the bone. The periosteum is divided and separated and the bone divided at a slightly higher level.

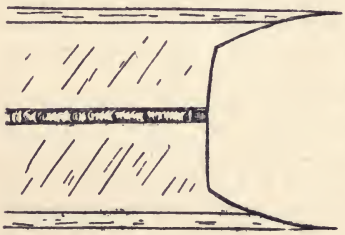


FIG. 57.—Diagrammatic view of a recommended method of amputation.

Use of the Guillotine Method of Amputation.—This method was originally introduced for established sepsis, when the tissues were glued together by exudation.

Its use has been extended to primary amputations, and here it has its uses as well as its abuses.

The guillotine method may be called for under the following conditions:—

(1) A shattered leg with multiple wounds of the thigh when a clean thigh amputation cannot be done.

(2) In the lower third of the leg when the upper leg is the seat of multiple wounds.

(3) In the foot when the alternative is a Syme's amputation with a considerable risk of suppuration, infection subsequent to a Syme's amputation being exceptionally bad.

(4) In gas gangrene of the leg when the heads of the gastroc-

nemius muscle if involved can be dissected out. In such cases the guillotine method involves much less shock than an amputation through the thigh.

There are certain distinct contra-indications to the method.

Its general adoption in cases of gas gangrene infection is not to be recommended, as the disease tends to spread so rapidly in a vertical direction.

It is an especially bad operation when performed as a primary measure through the fleshy thigh; in this situation it should be reserved for a rapid amputation through a shattered femur, and even in such cases short flaps can as a rule be made.

Qualities of a good Stump.—From the prosthetic point of view the chief qualities of a good stump are as follows:

1. *A satisfactory Length.*—It is a good rule to make an amputation stump as long as possible; when a secondary amputation is probable this is a most important detail.

2. *A good mobile Covering.*—This is secured by cutting efficient flaps whenever possible. The flaps would always contain deep fascia and usually muscle, and they should be of sufficient length to cover the stump loosely without undue puckering. When flaps are cut but not sutured undue retraction is prevented by continuous extension applied to the flaps.

3. *A firm non-adherent Cicatrix.*—Whenever possible the end of the bone should be covered with the deeper soft parts; by so doing adhesion of the scar is prevented.

4. *Freedom from Pain or Tenderness.*—The principal nerves should be cut short at the primary amputation. As painful nerve ends sometimes occur in spite of original high division, certain modifications have been introduced in the treatment of the nerves—crushing of the nerve and ligature of the sheath at the crushed part, suture of the nerve sheath over the divided end, and suture of the nerve end after the removal of a terminal wedge.

5. *Efficient Shrinkage of the Stump.*—This is an important matter in the eventual fitting of the artificial limb.

6. *Free Mobility of the Joints above the Site of Amputation.*

Sites of Amputation.

In this relation we quote largely from the official memorandum which has recently been issued, and we wish to acknowledge our indebtedness for permission to make this abstract.

Amputations of the Upper Extremity.—*Thumb, Fingers, and Hand.*—The importance of preserving as much as possible of the thumb or of a finger can scarcely be insisted on too emphatically. Although as a rule as much as possible of the hand should be preserved, yet in cases of extensive destruction of one or two metacarpal bones, with loss of flexor and extensor tendons, it may be better to amputate the affected finger early.

Amputation at the wrist should never be done if it is possible to retain any part of the hand or carpus.

Forearm.—The best amputation in this region is at the junction of the middle and lower thirds; above this point the stump should be made as long as possible. Short forearm stumps, *e.g.* 2 to 4 inches below the tip of the olecranon, are difficult to fit with artificial limbs. When it becomes absolutely necessary to employ such short stumps, it is recommended that the flexor muscles of the wrist and fingers, the supinator longus and the extensor carpi radialis longior and brevior, should be removed at their humeral attachments so as to leave the anterior surface of the forearm as flat as possible.

Elbow-joint.—Amputation immediately above the joint should be chosen in preference to amputation through the joint. In order to avoid a bulbous stump it is advisable to divide the humerus immediately above the epicondyles.

Arm.—The humerus should be divided at as low a point as possible: an exception to this is the amputation we have

mentioned immediately above the elbow-joint. In all other situations as much as possible of the bone should be preserved.

Near the shoulder-joint the preserving of even a small portion of the bone is important. Special care should be taken to prevent adduction contracture of the stump.

Amputations of the Lower Extremity. — *Toes.* — The question of the amputation of toes is very different from that of the fingers. Single toes are very apt to become deflected, deformed and painful, and therefore a single toe should never be left. The heads of the metatarsal bones, and especially the head of the great toe, should be kept whenever possible.

Foot.—In the region of the foot Syme's is undoubtedly the best amputation. The flap should be so shaped that it fits closely over the ends of the bone, the bones being divided a quarter of an inch above the articular border of the tibia.

When the wound of the soft parts is such as to prevent a classical Syme, the operation may be modified by cutting a long internal sole flap (Roux) or by using an anterior flap.

Lisfranc's amputation gives good results when it is assured that the ends of the tarsal bones are well covered; this very necessity often obviates the operation in wound conditions. Chopart's amputation is good provided that the heel is not allowed to become drawn up and that the tarsal bones are effectively covered.

Neither Pirogoff's nor the sub-astragaloid amputations offer any advantage over a Syme.

Leg.—The best amputation through the leg is that in which the tibia is divided from 4 to 8 inches below the knee-joint. If a guillotine amputation is to be done it should be performed at the lowest possible level so as to allow of subsequent re-amputation at the most suitable spot.

In these amputations a terminal scar should be avoided; anterior-hooded, antero-internal, and postero-external flaps are suitable. The sharp anterior border of the tibia should be

sloped so as to prevent pressure on the skin. The fibula should be divided ¾ inch above the end of the tibia, and if the portion of tibia is less than 3½ inches long, the fibula should be entirely removed. Even a short length of the tibia (1 inch) is preferable to an amputation through the knee-joint.

Knee-joint.—As a life-saving measure disarticulation through the knee-joint is a valuable operation. A long skin flap should be used and if possible the patella should be removed; should the conditions be such that speed is all important the patella may be left to be used at a subsequent operation to cover the end of the femur.

The Condyles of the Femur.—This operation has the disadvantage common to disarticulation through the knee-joint that it is difficult to fit a limb with an artificial knee-joint.

A Stokes-Gritti amputation should not be attempted as a primary operation, as it is liable to be followed by non-union of the patella and femur.

Lower to Middle Thigh.—The stump in the thigh should be as long as possible. The most favourable site for amputation is one inch above the adductor tubercle. The flaps should be cut in such a way that a terminal scar is avoided. Care should be taken that the stump does not become flexed or adducted.

Upper Thigh.—In this situation as long a stump as possible should be left; every effort should be made to avoid a disarticulation through the hip-joint.

The Hip-joint.—The shock associated with this operation is so great that it is very rarely justifiable as a primary measure. If it is imperative the anterior racket incision is the best, the femoral vessels being first ligatured.

CHAPTER XVI

TRANSFUSIONS AND INFUSIONS

Under this heading we shall not consider the procedure by which saline fluid is introduced into the body by the subcutaneous route or by proctoclysis. These methods are already sufficiently well known and recognised. Accordingly we shall limit our attention to intravenous infusions and transfusions.

Indications for.—In the surgery of war there are certain clearly defined indications for the use of intravenous infusions.

(1) In cases of severe primary and secondary haemorrhage.

(2) In many cases of shock.

(3) In certain cases of toxaemia and acidosis.

Apart from an actual loss of blood, a persistently low blood pressure may be accepted as an indication for transfusion.

The Ideal Fluid for Transfusion.—It is but natural that human blood should be the ideal fluid for introduction into the body. It is the only method we at present possess by which haemoglobin can be introduced, and it alone possesses corpuscles with an oxygen-carrying capacity.

The Substitution of Fluids for Blood.—There exists at present a great and urgent need for an injection fluid that can be satisfactorily employed instead of blood for transfusion in cases of haemorrhage and shock. It is common knowledge that during heavy fighting a Casualty Clearing Station may

be crowded with men who have lost too much blood to be operated on, who cannot be revived by means of salt solution and supportive measures, but who would undoubtedly respond to blood transfusion. For the latter neither time nor donors may be available. A number of fluid substances have been suggested, and we propose to consider some points in regard to them.

The Relative Importance of the Plasma and of the Red Cells of the Blood. — The importance of the plasma has recently been investigated by Abel, Rowntree and Turner.[1] They have demonstrated that the healthy body will withstand and quickly repair great losses of the fluid elements of the blood. The ability to withstand similar losses of red cells has been considered by Rous and Wilson.[2] They have shown experimentally at least that when the haemoglobin is reduced by not more than three-fourths—as, for example, from 80 to 20 per cent—no marked change occurs: there are temporary quickening of the respiration, a lowering of body temperature, and a contraction of the peripheral blood-vessels. These changes are only temporary, and within a few minutes the individual is able to adapt itself to the altered conditions.

When, however, four-fifths or slightly more of the haemoglobin had been removed, the animal after an interval of panting and somnolence succumbed in three to six hours.

Rous and Wilson have pointed out that importance is to be attached to the proportional amount of haemoglobin rather than to the absolute quantities. For example, a rabbit with an initial haemoglobin of 80 per cent will withstand a reduction to 20 per cent, whereas this is fatal to an animal having 100 per cent to begin with.

From the above investigation and from others of a similar nature the fact has been established that even after

[1] *Journal Pharmacol. and Exper. Therap.*, 1914, 5. 625.
[2] *Journ. Amer. Med. Assoc.*, 1918, 70. 4. 219.

the severest acute haemorrhage sufficient haemoglobin (red cells) is retained to maintain life if only the fluid bulk can be restored.

The Relative Merits of Blood Substitutes.—(*a*) *Physiological Sodium Chloride.* — For many years the intravenous infusion of physiologic sodium chloride (0·9 per cent sodium chloride) has been used extensively in shock and in collapse after haemorrhage. It would appear that the introduction of this solution induces a condition of hydraemic plethora, that is, a dilution and increase of the total volume of the blood. The kidneys, the skin and the lymph channels excrete the excess of fluid, there is a profuse perspiration, and presently the blood is actually less in bulk and more concentrated than it was before. As a result of the introduction of from one to two pints of the solution the blood pressure is immediately raised by an extent of from 40 to 50 mm. of Hg: within half an hour, however, the pressure begins to fall, and it declines steadily until within one or two hours after the injection it has reached a lower level than before the infusion.

Therefore it cannot be said that physiologic sodium chloride is in any way a reliable blood substitute.

(*b*) *Ringer's Solution and Hypertonic Saline Solution.*— Ringer's solution has a composition as follows:—

Sodium Chloride, 0·9 per cent.
Potassium Chloride, 0·03 per cent.
Calcium Chloride, 0·05 per cent, and a trace of Sodium Bicarbonate.

The Medical Research Committee have issued a formula for a hypertonic solution of which we have had some experience. It is constituted as follows:—

Sodium Chloride, 2 gm.
Potassium Chloride, 0·05 gm.
Calcium Chloride, 0·05 gm.
Water, 100 c.c.

Our experience of these solutions has been that while they give somewhat better results than physiologic sodium chloride, there is still a great deal to be desired. With the introduction of the fluid the blood pressure rises: it is maintained for a slightly longer period than is the case with normal saline, but within one and a half to two hours it has again fallen. Their benefit is therefore very temporary, but this much at least may be said, that the hypertonic solutions are preferable to physiologic saline, the reason being that they are probably retained for a longer time in the blood-vessels, thus producing a more constant blood pressure.

(*c*) *Hypertonic Glucose and Dextrin Solutions.*—It is interesting to determine the effects of these solutions since it has been stated that they draw fluid into the circulation. The solutions employed are 8 per cent dextrin (Merck) in salt solution and 5·4 per cent glucose in Ringer's solution, a fluid with twice the tonicity of blood. These fluids have been found to exert only a slight transient effect in raising the blood pressure.

(*d*) *Horse Serum.*—The indications are that horse serum would prove an effective blood substitute except for the risk of inducing sensitisation and causing anaphylactic shock. Even in a non-sensitive man the injection of a large amount causes serum sickness. On account of these objections the method cannot be entertained as a practical scheme. Under the conditions of the battlefield, while it might well save many lives, it would certainly cause some deaths.

(*e*) *Gelatine-containing Fluids.*—These have often been used as blood substitutes. Hogan[1] advises 2·5 per cent. This solution undoubtedly restores blood pressure better than salt solution, but the effect is soon lost, the pressure falling off in the course of fifteen to twenty minutes nearly to the original level. To be of value higher percentages of gelatine are required. In some instances 4 per cent gelatine restores the blood pressure

[1] *Journ. Amer. Med. Assoc.*, February 17, 1915, p. 721.

permanently, but in others it does not. Six per cent gelatine is always effective.

This method, however, has certain disadvantages. It is essential that only the purest forms of gelatine should be employed on account of the liability of tetanus infection being present: these forms are now difficult to obtain. Further, the solution requires to be made up with extreme care.

(*f*) *Gum Acacia Solution.*—Bayliss, who originally advised either 6 per cent gelatine or 7 per cent gum acacia as blood substitutes, has recently advocated the latter. It possesses certain very real advantages. It is more uniform in constitution than commercial gelatine, and, being protein free, it does not induce anaphylaxis or the severe reactions which occasionally follow gelatine injections.

On the British front, when acacia solutions were first used there was an avoidance of the higher percentages in favour of a 2 per cent fluid. The results, while encouraging, left something to be desired. A 2 per cent solution at first raises the pressure to normal, but it drops off within a few minutes to the danger point. Four per cent was more satisfactory, as the secondary drop in pressure, being slow, is better compensated; but 6 or 7 per cent is required if one is to bring back the normal pressure in an organism depleted of its fluid reserves. Except for the blood or plasma of other human beings, fluids containing 6 to 7 per cent of gum acacia are the best at present available for the purpose of blood substitution.

To give the solution the requisite salt content to prevent haemolysis 1·5 to 2 per cent of sodium bicarbonate is added.

Bayliss[1] gives the following directions for the preparation of the solution:—

"The gum . . . used was sold as 'Turkey elect,' and was in medium-sized lumps of a pale yellow colour and transparent.

[1] Bayliss, *Report to Medical Research Committee*, November 25, 1917, p. 20.

A solution was slightly opalescent, remaining so when filtered, so that the turbidity was due to colloid particles.

"To make a 6 per cent solution dissolve the required quantity in tap water on a warm bath; it is better not to use distilled water on account of the so-called water fever sometimes produced. Cool to room temperature, add 2 per cent sodium bicarbonate in powder: on shaking, a precipitate of calcium carbonate separates. If possible allow to stand for twenty-four hours. Filter through Chardin paper or centrifuge according to convenience. The solution will probably still retain a colloidal suspension of part of the calcium carbonate, but this is of no consequence. The next step is to sterilise in sealed bottles in steam or in the autoclave. It is important that no carbon dioxide escapes. Should this be the case, the solution becomes too alkaline, and the gum loses viscosity by chemical changes and becomes brown in colour. Sometimes a small amount of calcium carbonate may deposit, but this did not occur with my sample of gum. In any case it forms a layer on the bottom of the bottle. What actual pressure is produced in the bottle I am unable to state precisely, except that I found it to be well below 40 mm. of mercury. A strong glass bottle will withstand this comparatively low pressure; the bottles with a porcelain stopper and rubber washer, held by a strong wire clip, which are in common use for sterilised milk, have been found strong enough and very suitable for the purpose. . . . The carbon dioxide is, of course, redissolved in cooling. The whole bottle is warmed before injecting the contents."

Bayliss advises that in cases of severe haemorrhage, when transfusion of blood is not possible, it may be found of value to add to the gum solution a certain proportion of washed blood corpuscles.[1] The supply of oxygen to the tissues is

[1] It has been pointed out that the addition of gum to preserved red blood corpuscles has a tendency to induce clotting, and in view of this the addition of washed blood corpuscles to gum acacia solution is not recommended.

increased thereby. If this is done the percentage of gum should not be higher than 5 per cent on account of the viscosity.

Technique of Injection.—It is important to insist upon the fact that whatever the type of injection fluid the introduction should be a gradual one, more especially in the case of the more viscous types of fluid such as gum acacia. For the introduction of one pint of the solution at least twenty minutes to half an hour should be allowed.

The amount to be injected will be governed largely by the response which the blood pressure shows. Large injections should be avoided, and it is rarely advisable to inject more than fifteen to twenty ounces at one time.

The fluid may be introduced by passing a hollow needle through the skin into the vein. If much blood has been lost the vein may be so collapsed that this is difficult or impossible, in which case it is necessary to expose the vein and introduce a canula.

The device called "fixe veine" by Creuze and Grimberg, sold by Adnet of Paris, may be found useful to keep the vein in position when a subcutaneous introduction is being made (Bayliss).

Blood Transfusion.—*Selection of Cases.*—Transfusion of blood has been performed with increased frequency during the past year, and has been of the greatest use in cases of severe primary or secondary haemorrhage as well as in many cases of shock. Many cases in these classes hitherto considered as inoperable, and others as exceedingly bad surgical risks, may often be revived to a degree which not only permits of radical operative measures, but ensures a good prospect of ultimate recovery. There are other cases in which the post-operative condition is one of progressively increasing shock, due to the initial loss of blood and to the severity of the operative measures required; in these blood transfusion is a permanent feature of immense value.

Owing to the difficulty in obtaining an adequate supply of donors, the procedure has necessarily been limited, and so far it is generally reserved for the worst type of case in which blood transfusion offers the only possible chance of success.

Selection of Donors.—The donor should be a healthy adult, and the loss of the amount of blood which is generally used is rarely felt. In view of certain recorded instances of the transmission of syphilis from donor to patient (McClure) it is well, if possible, to exclude this possibility; a tactful explanation and questioning is sufficient, a Wasserman reaction is generally out of the question.

When the prospective donor is found, his blood should be tested with that of the patient for iso-agglutinins and iso-haemolysins. As early as 1875, Landois[1] showed the incompatibility of certain bloods, and in 1901 Landsteiner[2] divided individuals into three groups according to the iso-agglutination properties of their bloods. In 1910[3] Moss added a fourth group. Major Lee of the United States Medical Service published last November[4] the details of a simple and rapid method for the selection of suitable donors for transfusion by the determination of blood groups.

Using the arbitrary classification of four groups, it is found that approximately 8 per cent of individuals fall in Group I., nearly 40 per cent in Group II., 10 per cent in Group III., 42 per cent in Group IV. (Lee).

The important consideration is that the serum of the recipient does not agglutinate or haemolise the red corpuscles of the donor. The fact that the donor's serum may agglutinate and haemolyse the recipient's red corpuscles does not contra-indicate transfusion for the reason that in an ordinary trans-

[1] Quoted by McClure, *Journ. Am. Med. Assoc.*, 1916, lxvii. p. 794.
[2] *Wien. klin. Woch.*, 1901, xiv. p. 1132.
[3] *Bull. Johns Hopkins Hospital*, 1910, xxi. p. 63.
[4] *B.M.J.*, Nov. 24, 1917, p. 684.

fusion one adds from about one-fifth to one-twelfth of the total blood volume of the patient, and in this dilution the patient's cells are amply protected by his own serum.

The following figures tabulate the reaction of serum and cells :—

Serum of Group.	Cells of Group.				No. of Individuals in Group.
	I.	II.	III.	IV.	
I. . .	0	0	0	0	I. = 88 %
II. . .	+	0	+	0	II. = 40 %
III. . .	+	+	0	0	III. = 12 %
IV. . .	+	+	+	0	IV. = 42 %

+ = agglutination. 0 = no agglutination.

If a patient is in Group I. he can receive blood from any donor because the serum of Group I. will neither haemolyse nor agglutinate the red cells of any group. A Group I. person is therefore known as the universal recipient.

If a patient is in Group IV. his blood can be transfused into any patient because his cells are agglutinated and haemolysed by no group. Group IV. is therefore spoken of as the universal donor group.

The Method of determining to which Group a Blood belongs.—*When "Test" Sera are available.*—The following method is described by Captain Robertson, M.O.R.C., U.S.A., in his report to the Medical Research Committee on Blood Transfusion, April 4, 1918:—"In order to determine the group to which a blood belongs it is necessary to have known sera of Groups II. and III. only. These are obtained by strict precautions from persons belonging to these two groups. One per cent chloroform is added to the serum as

a preservative, and it is kept most conveniently in small drop bottles (glass pipette through stopper with rubber nipple) sterilised beforehand. The test may be performed in various ways. The following one devised by Vincent has proved satisfactory. A drop of Group II. serum is placed at one end of a clean microscopic slide, and a drop of Group III. at the other end. A small drop of blood is obtained from the ear of the person to be tested, and transferred on the end of a match stick to each drop of serum and well mixed with it. Care is taken to break off the ends of the match between drops in order to avoid mixing the two sera. The slide should be tipped frequently from side to side during the test. A positive test shows definite clumping beginning in a few moments, which soon becomes well marked. A negative test remains as a smooth film. The test usually gives sharp readings."

The grouping of the blood may be summarised in the following table :—

If Group II. serum produces agglutination the blood belongs to Group III.

If Group III. serum produces agglutination the blood belongs to Group II.

If both sera produce agglutination the blood belongs to Group I.

If neither sera produces agglutination the blood belongs to Group IV.

When no stock sera are available the procedure is as follows :—

When "Test" Sera are not available.—"A small amount of blood is collected from a patient (1 c.cm. from the ear or finger is sufficient) and allowed to clot. The serum is then obtained. One drop of this serum is placed upon a slide and mixed with a drop of suspension of blood of the donor taken into 1·5 per cent citrate solution. (A few drops of

blood taken into approximately ten times the amount of 1·5 citrate solution and shaken. It is very important that the blood be dropped directly in the citrate, and should not be partially coagulated.) The test will appear in a few moments, and is best examined under the microscope, when, in the event of a positive test, marked agglutination will be evident. The test will also be evident macroscopically. In the event of a negative test it is a wise precaution to raise the cover-glass, and after making sure that the serum and cells are well mixed, to examine the preparation again. The only possible source of confusion is the appearance of rouleaux of the red corpuscles, indicating a too thick emulsion. If the test is negative, transfusion may be regarded as entirely safe" (Lee).

With the serum of Groups II., III., and IV. a number of donors are tested and the names and groups are noted. In an emergency, a donor from Group IV. can always be employed. If there is sufficient time, the patients' blood is also grouped in order that donors from groups other than IV. may be employed. If blood tests are not available the surgeon should wait one full minute after injecting the first ounce of blood, in order to be able to recognise the symptoms of incompatibilities (see p. 280).

Reaction following Transfusion of "Compatible" Blood.—Even in those cases in which both donor and recipient have been found to belong to the same group, febrile reactions are apt to follow transfusion. Rigors appear in a small proportion, about 10 per cent; fever is noticed in about 25 per cent. The rigors have followed within half an hour of the transfusion, and the temperature in the febrile reactions, apart from the sudden rise accompanying the rigor, usually reaches a maximum of 102° to 103° F. on the following day, subsiding within forty-eight hours.

Reaction following Transfusion of "Incompatible" Blood.—A cross transfusion may result in an immediate fatality. In

others, there are destruction of the red corpuscles, haemoglobinuria, and marked jaundice, but without death; while in other cases the transfusion is followed by symptoms which are summarised by Colonel Cabot as follows: "Pain in the lumbar region, urticaria on the face, chest and abdomen, respiratory dyspnoea, vomiting or purging, symptoms of shock with dilated pupils, and sweating."

Dosage.—The amount of blood to be transfused depends upon the condition for which the transfusion is being done. If the procedure has been undertaken for a condition of shock in which there has not been a severe coexisting haemorrhage, an amount of from 400 to 500 c.c. may be sufficient. The amount should be gauged by the response of the blood pressure, and due regard should be paid to the danger of dilating an enfeebled heart.

When transfusion is being done for the treatment of acute anaemia due to haemorrhage, the blood lost should be replaced as fully as possible. It may be necessary to introduce such massive amounts as 1000 to 1200 c.c. Judgment must be guided by the blood pressure response and by the clinical improvement of the patient. Here again it is important to recognise the danger of dilating an enfeebled heart. Crile has pointed out that the work of the heart increases in geometric rates to the volume of blood, and it is easy to realise the risk which is involved in suddenly producing a rapid increase in the volume of blood when the heart is already tired out.

Methods of Transfusion.—(1) *Direct.*—(*a*) By anastomosis of vessels without an intermediate canula.

(*b*) By anastomosis of vessels with a canula.

(2) *Indirect.*—(*a*) By syringe transferred from needle in vein of donor to needle or canula in vein of recipient.

(*b*) By syringe with two-way tap leading to vein of donor and recipient.

(*c*) By use of a paraffin-coated receiver.

(*d*) By use of a receiver with the addition of an anti-coagulant.

Direct Anastomosis of Vessels.—Direct anastomosis of artery to vein by means of an end-to-end anastomosis is a matter of so great mechanical difficulty that it is rarely if ever employed.[1] Hull overcame the difficulty by inserting the artery of the donor into the recipient's vein. He describes his technique as follows:—

"An incision about 2 inches in length is made in the patient's arm over the median basilic vein.

"A similar incision is made over the radial artery of the donor. The artery is cleaned for about an inch, the lower end of the artery in the wound is clipped, digital pressure is made over the brachial artery, and the radial is cut above the clip. The end of the radial artery is pulled out of the wound, and a traction suture is tied through the wall of the artery.

"Two probes about an inch apart are passed under the vein for haemostatic purposes. A small cut is made into the vein (2 mm. in length); through this the needle bearing the traction ligature from the radial artery is passed. The needle emerges from the vein an inch above the incision. A second suture is now passed through the wound in the vein; this suture is used to close the vein when the artery has been inserted. By drawing upon the traction suture the artery is drawn in to the vein, the vein suture is tied, and the probes and digital pressure removed.

"The blood is allowed to flow until the donor feels faint. The artery is then clipped, pulled out, and ligatured. The whole procedure is carried out under local analgesia.

"It may be objected that making use of the radial artery as a canula involves a serious avoidable mutilation of the donor. This is not the case; ligature of the radial artery must be

[1] Full details of the various methods of direct transfusion will be found in Lexer-Bevan's *General Surgery*, p. 1008.

performed in any case, and the excision of an inch or so of the vessel makes no difference. The elasticity of the artery renders its use as a canula easy, and a considerable length of vessel becomes available through a comparatively small wound."

Though by this means the possibility of clotting is diminished the method has the disadvantage that there are no means of knowing how much blood is being transferred beyond the clinical improvement of the recipient and the faintness of the donor.

Anastomosis of Artery to Vein by means of a Canula.—This method has frequently been suggested, and in the *Lancet* of May 12, 1917, Fullerton, Dreyer and Bazett described a simple procedure which has given us satisfactory results. The transfusion is effected from the radial artery to a suitable vein, generally the median basilic. The apparatus consists of two glass or silver canulae connected by a short length (about 7 inches) of thin-walled transparent rubber tubing. The tubing and canulae are coated inside with a thin layer of hard paraffin, by Saxton Pope's [1] mixture or with sterilised liquid paraffin.

Technique.—Patient and donor are placed side by side in such a position that the arms are lying on a small central table as close together as possible, the wrist of the donor being opposite the elbow of the recipient. Radial artery and median basilic vein are exposed under local anaesthesia. A distal ligature is placed on the artery, and a light arteriorraphy clamp is applied proximally. Similarly with the recipient's vein. V-shaped incisions are made into each vessel. The arterial canula is first inserted, and by releasing the vessel clamp the tube fills with blood. On releasing the vein clip the transfusion is begun. We have slightly modified the procedure as follows. The canulae and tubes are kept immersed in a solution of sterilised liquid paraffin. Immediately before the connection between artery and vein is made, the rubber tube is drawn out

[1] *Journ. Amer. Med. Assoc.* lv., 1913, p. 1284.

between the finger and thumb and is maintained in a collapsed condition by applying light clips at each end of the rubber tube. Sufficient paraffin is left lining the tubes to prevent coagulation occurring. When the canulae have been inserted the tube clips and the vessel clips are removed simultaneously. In this way all risk of entering air is prevented, and the temporary vacuum inside the rubber tubing aids the commencement of the transfusion.

The method has the disadvantages that it requires a certain amount of technical skill, and also that it is difficult to estimate the amount of blood which is being transfused. It has been found by experience that a period of about twenty-five minutes is required in order to transfuse 1000 c.c. of blood.

The Syringe Canula Method.—This method was elaborated by Lindeman,[1] and it has many adherents. It necessitates the employment of two operators, several assistants, a number of large syringes, and two needle canulae. The following is a brief description of the technique :—

The needle canulae consist of two metal tubes fitting closely one inside the other, and passing through the inner tube is a hollow needle. (Each part projects a short distance beyond the point of the respective enveloping tube.) Eight or ten 20-c.c. record or all-glass syringes are provided.

The syringes and canulae are lubricated before use by drawing sterilised liquid paraffin through them. Several pints of warm and several pints of cold sterilised saline are kept in readiness.

The donor and recipient are placed on tables, and between the tables there is sufficient space for the operators and for stands holding the syringes and the saline solutions.

The arms are arranged in the most convenient way for each operator. The needle canulae are inserted simultaneously into the veins of donor and recipient. Tourniquets are used to

[1] *Amer. Journ. Obstr.*, N.Y., 1913, vi. 28.

render the veins more prominent. In the case of the donor the canula is inserted towards the hand; in the recipient it is inserted towards the shoulder. The canulae are inserted slowly, and as soon as blood begins to flow the hollow needle or trochar is removed, the canulae thrust further into the vein, and the inner canula removed.

A syringe is now attached to the donor's canula [1] and filled; while this is being done a syringe full of warm saline is attached to the recipient's canula and the saline slowly injected. As soon as the donor's syringe is filled with blood it is disconnected and passed to the other operator, who disconnects the saline syringe and injects the blood.

After the withdrawal of each 20 c.c. of blood a syringeful of saline is attached to the donor's canula and the saline injected: this prevents clotting in the canulae system.

Each blood syringe is washed out with cold saline after use. The whole process is repeated as rapidly as possible. From time to time it is an advantage to lubricate the syringes with fresh sterilised paraffin.

There is an advantage in having orderlies who are specially trained in the use of the tourniquets; it should be their duty to release the tourniquet pressure momentarily between the syringes—this lessens the loss of blood.

It is important to observe that no air is injected. Repeated carelessness in this detail may have a disastrous cumulative effect.

The Two-way Tap Syringe Method.—There are several varieties of apparatus of this type in use; the best is probably the two-way stop-cock of Unger.[2]

[1] Major Bruce Robertson, C.A.M.C., uses two 2-inch rubber tubes provided with metal tips to fit the needles and syringes. By their use the canulae are less likely to be displaced from the veins. *Brit. Med. Journ.*, July 8, 1916.

[2] Unger, *J. Amer. M. Ass.*, Dec. 29, 1917, p. 2159.

The mechanical difficulties in connection with the two-way tap are very great, and we cannot recommend the method for use in the field.

The Use of a Paraffin-coated Receiver.—The principle of this method is that the donor's blood is received directly from the vein into a paraffin receiver of known capacity.

There are a number of models in use; the original types were the glass cylinders of Kimpton and Brown [1] and the pipette canula apparatus of Satterlee and Hooker.[2]

Tubes are now supplied by the army, and an excellent apparatus can be improvised from the ampoules in use for the Carrel treatment of wounds. The narrow end of the ampoule is drawn out into a canula fine enough to insert into a vein, the ampoule is marked off into c.c. capacity, the open end of the tube is fitted with a rubber stopper through which a short glass tube passes, and the whole interior is carefully covered with hard paraffin. The best method of accomplishing this last and often none too easy detail is to place a thoroughly clean glass tube or ampoule in a horizontal position together with dressings, etc., in the ordinary casket steriliser. Within the glass tube there are placed several pieces of hard paraffin. The whole is sterilised, and when the sterilisation is complete and the tube is still warm, the operator or nurse grasps the tube with sterile gloves and after a few rapid rotations the entire inner surface is coated with paraffin; cloths moistened with alcohol are rubbed over the outer surface of the tubes to hasten the setting. It is important that the paraffin should extend throughout the canular portion of the tube.

The Technique of the Transfusion.—The method demands an operator, an assistant, and an orderly or nurse. The beds or tables for donor and recipient are placed near each other and so arranged that the respective arms are close together. Large

[1] Kimpton and Brown, *Journ. Am. Med. Assoc.*, July 12, 1913.

[2] Satterlee and Hooker, *Journ. Am. Med. Assoc.*, Feb. 26, 1916.

superficial veins are chosen and rendered prominent by the application of an elastic tourniquet.

Under local anaesthesia the operator cuts down on one vein while the assistant exposes the other: the donor's vein is ligatured proximally while the recipient's vein is tied distally. A second ligature is passed under each vein and left untied; by

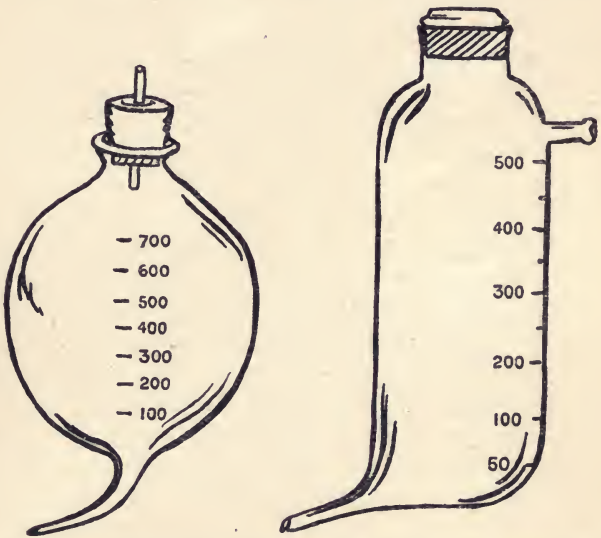


FIG. 58.—Different varieties of containers for use in blood transfusion: the first is a modification of the ampoule which is used in the Carrel-Dakin technique.

pulling upon its ends the blood is controlled when the veins are opened.

The donor's vein is opened by a small oblique incision made distally; the tension ligature on the vein is loosened, and the prepared receiver inserted distally. The tourniquet is tightened and the blood flow accelerated by getting the patient to carry out strong opening and closing movements with his hand. The

receiver rapidly fills with blood, usually at the rate of about 100 c.c. per minute. While the receiver is filling, the assistant has prepared the recipient's vein in a manner similar to that which we have described, the incision into the vein being made centrally. Pulling on the loose control ligature prevents the escape of blood, and the wound is covered with a swab soaked in warm saline.

When the requisite amount of blood has been collected in the receiver, the tourniquet is released, the thumb is placed over the open end of the receiver or over the air tube, and the canula is withdrawn from the vein. The moment the receiver is released the open end of the canula is closed with the finger; the receiver is tilted slightly to prevent the escape of blood. The receiver is carried to the recipient, the finger removed, and the canula inserted centrally into the recipient. The tourniquet has already been removed and the receiver is allowed to empty itself.

By means of a sterile pressure syringe inserted into the large end of the ampoule or attached to the air tube of the receiver, the pressure within the vessel is slightly raised and the introduction of the blood is thus facilitated. The inflow of blood should be gradual, about 100 c.c. per minute, and the patient is carefully watched for symptoms of distress. The tube is removed while it still contains a few c.c. of blood, the entrance of air being thus prevented. The control ligatures are now tied and the skin wounds closed. Immediately after the transfusion the receiver should be carefully washed out, at first with saline to remove all traces of the blood, then with warm water and soap to remove the paraffin, with chloroform to remove the last traces of the paraffin, and finally with alcohol and ether.

The use of a Receiver with the addition of an Anti-coagulant.—Various anti-coagulants have been recommended. Satterlee and Hooker[1] employed hirudin with satisfactory results; but it

[1] Satterlee and Hooker, *Arch. Int. Med.*, 1914, xiii. 15.

is difficult to guarantee the absence of toxic substances with hirudin, and serious symptoms have occurred in some of the later cases in which it was employed.

Three years ago Weil [1] published his experiments on transfusion of exsanguinated animals with citrated blood, and since then sodium citrate has been the anti-coagulant most commonly employed. Some workers assert that it has a toxic action when

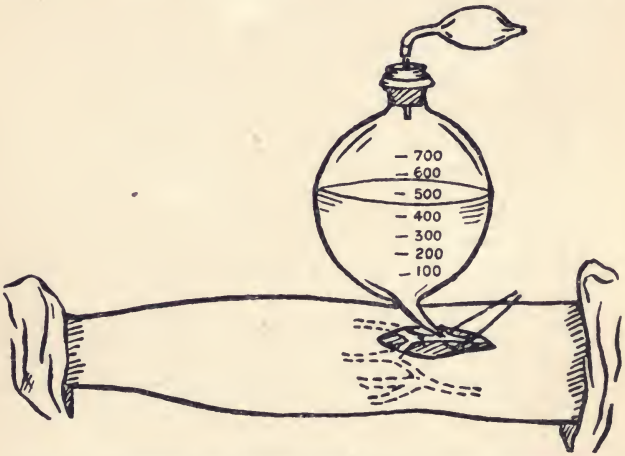


FIG. 59.—Diagrammatic view of the method of blood transfusion by means of the paraffined receiver.

used in adequate doses, but all the clinical and experimental evidence is opposed to this assertion. There are various mechanical devices by which the blood is drawn off from the vein, mixed with an appropriate amount of the sodium citrate solution, and afterwards injected into the recipient's vein under slight pressure.

It is perfectly efficient, however, to withdraw the blood from the donor by means of a needle or canula into a beaker containing the sufficiency of the citrate solution. The passage leading

[1] Weil, *Journ. Am. Med. Assoc.*, 1915, lxiv. 425.

from the vein to the citrate should be of large diameter, as short as possible, and absolutely clean. The blood must be mixed with the citrate at once. When the appropriate amount of the mixture has been obtained, the whole is injected intravenously into the recipient by any of the usual means.

As regards the strength of the citrate solution, Weil recommends a 10 per cent solution of the citrate, one part of the solution being mixed with ten parts of blood. It is generally sufficient, however, if it is ensured that the mixture contains ½ per cent of the citrate.

Robertson in his report to the Medical Research Committee recommends the use of an apparatus for the transfusion of citrated blood, and we quote his description from that report:

"A wide-mouthed, well-cleaned drug bottle with a capacity of 900 to 1000 c.c. will serve as the transfusion bottle. It should be short and wide rather than long and narrow, since this shape diminishes the length of intake tube necessary. Three marks are made on the bottle with a file: one at 660 c.c., one at the 760 c.c., and the other at the 860 c.c. levels, indicating 500, 600, and 700 c.c. of blood respectively. It is well to use a glass pencil also to make the marks more distinct. 160 c.c. of a 3·8 per cent solution of sodium citrate (isotonic), made up with freshly distilled water and filtered, is placed in the bottle, which is stoppered with a cotton plug wrapped in gauze. A second piece of gauze is tied on over the stopper and neck of the bottle. It is then autoclaved; one half-hour at 105 degrees centigrade should be the minimum. Where a number of transfusions are being given, half-a-dozen or more of these bottles are prepared at once.

"The needle (*a*) should be of a large bore; 1·5 to 2 mm. internal diameter was found to work well, and not more than 3·5 cm. long (1·5 inch). It should have a fairly large olive-shaped base. The needle is the most important part of the apparatus and requires careful attention. Before each bleeding

it should be carefully sharpened. The most important consideration in the sharpening is to produce a good spear point. If the point is well protected when not in use by a metal barrel or piece of rubber tubing, sharpening will require only a moment or so. The needle must be kept scrupulously clean,

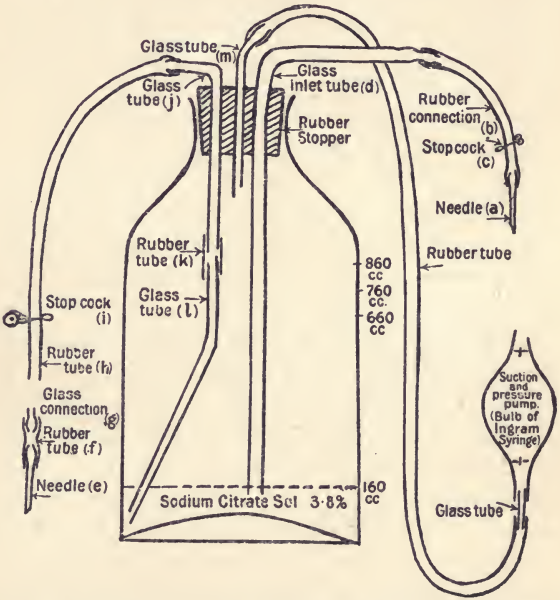


FIG. 60.—Citrate transfusion apparatus. (Captain Oswald Robertson.)

and after each bleeding should be washed out at once, all fragments of fibrin or clot removed from the base, and small pieces of cotton wool soaked in liquid paraffin thrust through the lumen with a stilette. The whole needle is well oiled before being put away. The rubber connection (*b*) should be flexible and not more than 8 cm. long (3 inches). The inner surface should be smooth and the lumen slightly smaller than that of

the glass inlet tube (*d*). If the rubber connection fits snugly over the base of the needle, tying it on is not necessary. The glass inlet tube (*d*) is made of a large bore glass tubing about 6 to 7 mm. internal diameter. It should extend below the level of the solution in the bottle.

"The transfusing needle (*e*) employed has a bore about half the size of that used for bleeding. The length is not important. As shown in the illustration, the needle is attached to a short glass tube (*g*) by means of a small piece of rubber tubing (*f*).[1] The free end of the glass tube is thrust into the end of the long rubber tube (*h*) after the needle is in the vein. The rubber tube (*h*) may be of any convenient length—6 to 8 inches. The glass tube (*l*) is bent so that the end projects into the lowest part of the bottle. In this way almost every drop of blood in the bottle may be given. The bulb of an Ingram syringe serves as a pump with the valve arranged as in the diagram. Suction or pressure can be made by reversing the ends.

"*Procedure of Bleeding.*—The donor's arm is extended at a right angle to the body. The skin of the anti-cubital space is scrubbed up with soap and water, and the sterilisation completed with alcohol. A tourniquet is applied to the arm high up, and a suitable vein is chosen, remembering that the needle is to be inserted towards the hand. It is very important to have as large a vein as possible. Opening and closing the fist and flicking the skin below the point chosen for venipuncture aid much in dilating the veins. At the point selected to puncture a small amount of novocaine is injected intracutaneously. The tourniquet is then released. The apparatus is assembled as shown in the diagram, great care being taken to keep all the open parts sterile. The stop-cock (*i*) is closed, and the open end of the rubber tube (*h*) protected with a piece of sterile

[1] A needle with a close-fitting metal connection is more easily handled. The metal connection is slipped into the open end of the rubber tube (*h*) beforehand.

gauze, which is conveniently held on with a pair of Spencer-Wells forceps. Sufficient pressure is made with the pump to fill the bleeding system with solution. When the air has been driven out of the needle, the stop-cock (*c*) on the connecting tube is closed. The pump bulb is reversed, so that suction can be made when needed. The apparatus is now ready for use.

"The tourniquet is again tightened sufficiently to make the veins stand out well, but not enough to obliterate the pulse. The cuff of a blood pressure apparatus makes an excellent tourniquet with a pressure kept at 50 to 60 mm. of Hg. A small nick is then made through the skin with the point of a scalpel. The bottle is placed on a stand close to the patient's arm in such a position that there will be no kinking of the rubber connection when the needle is in the vein. Slight suction is next made in the bottle. The skin opening is mopped dry with a piece of sterile gauze, and the needle inserted for a short distance beneath the skin before entering the vein. The stop-cock (*c*) is then opened and the needle is pushed into the vein immediately. The blood follows the column of solution down the tube without leaving an air space. A moderate degree of suction is maintained, and the donor continues to open and close his hand slowly, care being taken that he does not move his arm. It is essential to keep the needle immobile. The operator should hold it throughout the bleeding, steadying his hand against the donor's arm. With the free hand the bottle is given a rotary motion every few seconds in order to ensure thorough mixing of the blood. In doing this care should be taken to avoid pulling on the needle. With those precautions 500 to 700 c.c. of blood can be easily and quickly obtained. If clotting occurs for any reason, such as the needle slipping out of the vein or air leakage, and the blood ceases to flow, the tourniquet should be released, the stop-cock closed, the needle withdrawn from the vein, and another attempt made with a fresh apparatus (needle, rubber connection,

and glass tube), using the same receiving bottle. It is usually better to take the other arm. When the blood has reached the desired amount, the tourniquet is removed, the stop-cock closed, and the needle withdrawn. The bottle is again agitated for a few seconds.

"If the donor's veins are small and the needle method fails, the vein can be cut down upon and a canula used. Inserting a canula into a vein is more difficult and time consuming than the needle method, and offers greater possibility for infection.

"The bottle of blood is placed in a glass jar containing water of about body temperature, in which it is kept during transfusion. The pump is reversed and the blood is now ready for transfusion. It will be noted that a column of blood is left in the intake tube after the bleeding has been stopped. This is done in order to avoid drawing into the bottle any little clumps of fibrin which may have begun to form immediately after the cessation of blood flow through the tubes. Leaving this blood does no harm. The blood should be given as soon after the bleeding as possible. If it is left standing for some time, changes may occur which make the blood less beneficial or even toxic.

"*Procedure of Transfusion.*—The recipient's arm is prepared in a manner similar to that described for the donor and a small amount of novocaine injected into the site chosen for the vein puncture. It is well to tie the rubber stopper down to the bottle with two strips of adhesive plaster in order to prevent it from flying out when the pressure increases. After these preparations have been completed, sufficient pressure is put on the pump to fill the transfusing system with blood. The stop-cock (*i*) is opened to fill the tube with fluid, then closed. The tourniquet is next tightened. As soon as the needle enters the vein blood flows out through the short glass tube; the tourniquet is immediately released, the apparatus is

connected up, the stop-cock opened, and the pump started. This technique is simple, and if carried out carefully there is no danger of forcing air into the vein. The operator should hold the rubber-glass joint of the needle connection firmly throughout the transfusion. If the veins are collapsed or constricted, as is the case in certain patients with shock and haemorrhage, it may be necessary to cut down on the vein and use a glass or silver canula instead of the needle. Care should also be taken to close the stop-cock before the air bubbles begin to pass up the tube.

"*Discussion.*—The question may be raised as to whether it may not be better to coat the inside of the bottle and tubes with paraffin. Theoretically this would be a good thing, and in 'peace' times it can be carried out. In rush periods, however, it is quite impracticable on account of the time required for the technique of the coating. Furthermore, judging by the excellent results obtained without the use of paraffin, it seems questionable whether a paraffin coating is necessary.

"An 'isotonic' solution of sodium citrate is used instead of the 10 per cent solution customarily employed, since it is felt that it maintains more nearly normal conditions for the blood. The amount of sodium citrate contained in the 160 c.c. of 'isocitrate' is approximately 6 grammes. No harmful effects have ever been observed from the injection of this quantity of citrate, which is very much less than the supposed toxic dose. 0·5 per cent citrate has been shown to be sufficient to prevent clotting when well mixed with blood. When 500 c.c. blood are drawn into 160 c.c. of a 3·8 per cent solution the resulting mixture is 0·9 per cent citrate. With 700 c.c. blood it is 0·7 per cent. An amount of blood as large as 800 c.c. may be taken into this amount of citrate with safety if the blood flow is well maintained and the blood and citrate are well mixed. The sodium citrate in this mixture equals 0·6 per cent. In bleeding quantities over 700 c.c. the flow through

the needle frequently begins to slow up and mixing the blood and citrate becomes more difficult.

"Aside from the chief advantage of its being a 'one man's job,' this method has several other considerations in its favour. The apparatus can be made from materials easily obtained and takes very little time to prepare. The technique of transfusion is simple and quickly carried out. The bleeding can be done in a conveniently arranged room outside the resuscitation ward. The blood is then carried into the ward and given at the bedside without the necessity of moving the recipient, thus avoiding injury, which is often done to the patient in shock by moving him to the operating theatre or even on to a table near by."

The Injection of Preserved Red Blood Corpuscles.—It has been suggested that when transfusion of whole blood is for any reason impossible, there are advantages in injecting, suspended in some medium, red blood corpuscles, which have been citrated and preserved. They possibly retain some power as oxygen carriers and they certainly assist in preserving blood volume and pressure in so far as they do not tend to escape out of the blood-vessels as fluids do. Hedon in 1912 first showed that blood corpuscles could be preserved and subsequently reinjected into the blood stream, and in 1914 Jurevitch and Rosenberg washed red blood corpuscles in a solution of sodium chloride and sodium citrate, afterwards demonstrating that in this solution their vitality could be preserved for several hours.

Peyton Rous and Turner described a method by which washed blood corpuscles may be preserved for three or four weeks.

They employed a solution containing two parts of isotonic (3·8 per cent) sodium citrate and five parts of isotonic (5·4 per cent) glucose.

Captain Robertson, M.O.R.C., U.S.A., has carried out a large amount of exceedingly valuable work on the subject, and

he has evolved a method by which transfusion of blood on this basis can be applied in war work.

In the following account of the method we quote very largely from Captain Robertson's report to the Medical Research Committee.

Separate stock solutions of the sodium citrate and of the

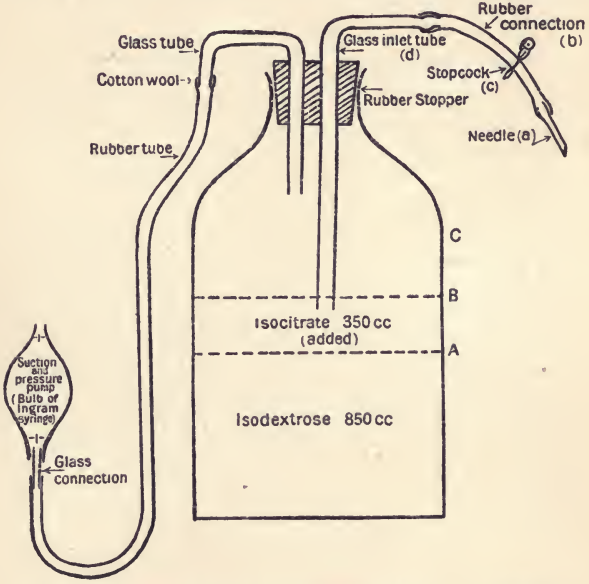


FIG. 61.—Bleeding bottle for preserved blood. (Robertson.)

glucose should be kept in readiness. On account of the difficulty in weighing out and dissolving liquid glucose it is convenient to make up a large quantity of a 20 per cent solution and to sterilise it so that it may keep (Robertson). To make isotonic glucose (5·4 per cent) 287 c.c. of the concentrated solution is diluted with distilled water to 850 c.c.

The blood is secured from the universal donor group (Group

IV.) and it is mixed with the solution (two parts of isocitrate and five parts of isoglucose) in the proportion of 500 c.c. of blood to 1200 c.c. of the solution. Robertson recommends that the donor should be bled directly into a stout bottle (Winchester) containing the glucose citrate solution. The

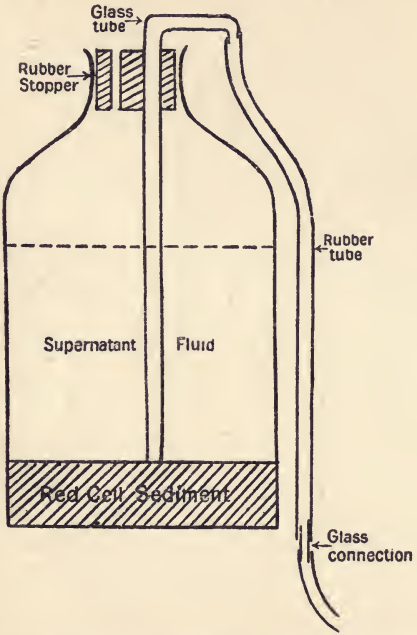


FIG. 62.—Apparatus for syphoning off supernatant fluid. (Robertson.)

needle rubber connection and glass inlet tube are identical with those described for the citrate method and the procedure of bleeding is the same. When the required amount of blood has been obtained, the bottle is given a rotatory motion to mix the blood with the solution and is closed with a sterile gauze plug. The vessel is labelled with the name of the donor,

the date, and the amount of blood; it is placed in an ice chest and the blood allowed to sediment. Sedimentation takes place rather slowly, and when 500 c.c. of blood have been originally withdrawn four or five days must elapse before it has settled sufficiently for use. Should the blood be required for use earlier than four or five days, smaller quantities of blood

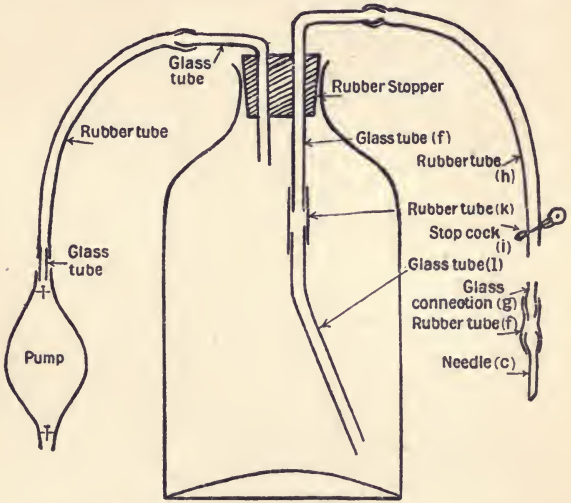


FIG. 63.—Apparatus for transfusion of preserved blood. (Robertson.)

should be originally added to the solution: 300 to 400 c.c. will have settled sufficiently for use in three days.

When sedimentation is complete the supernatant fluid is syphoned off with aseptic precautions. The supernatant fluid should be of a whitish or yellowish appearance. A pink coloration is suspicious, as it suggests an infection of the fluid with resulting haemolysis. Such a fluid should be discarded. While sedimentation is occurring, the supernatant fluid may show a pink coloration during the first two or three days, but this is of no consequence, as it simply means an irregular settling

of the corpuscles. When blood has been kept for four weeks or more the supernatant fluid becomes coloured as the result of disintegration of the red cells; the colouring gradually deepens, and of course such a fluid is quite unfit for use. If the blood has been stored for some time, the cells may have sedimented to a volume below the original volume of blood withdrawn. In such a case a diluting fluid is added to bring the volume of the cell suspension to at least that of the original amount of blood. Normal saline may be used as the diluent. A 2·5 per cent solution of gelatine in normal saline has been used for the same purpose, on the ground that being a colloidal solution it will remain in the circulation for a longer period than normal saline.

It has been suggested to employ 2 or 3 per cent gum acacia solution for the same purpose, but as the gum appears to induce clotting of the red cells its use cannot be recommended.

The blood cell suspension in its original condition or diluted is now rotated gently within the bottle and filtered through two layers of sterile gauze into the transfusion bottle. This is a wide-mouthed sterilised bottle fitted up in the way which has been described for the transfusion of citrated blood, except that of course the blood inlet tube is omitted. The transfusion is given in the way which has been described for the citrate method.

This method of transfusion has great possibilities of use in Casualty Clearing Stations. Large amounts of blood may be stored for use and the trouble of obtaining a number of individual donors is avoided. The transfusions can be given quickly and simply.

The method has only lately come into use, and up to the present its use has been limited, but the indications are that it will prove of immense value.

The Choice of Methods.—We believe that the "Citrate" method is by far the best for all practical purposes. It is simple, efficacious, and practically devoid of risk.

CHAPTER XVII

INJURIES TO THE EYES

This chapter is not intended to convey any expert detailed account of the treatment of eye injuries; it is meant rather to outline the treatment which is expected of a medical officer at a Casualty Clearing Station who pretends to no special training in eye work and yet who constantly is being brought into touch with these types of wounds.

The rules which ought to guide one may be summarised as follows:

(1) Carry out as little operative interference as possible, and let this be limited to excision of the eye and cleansing and drainage of wounds of the orbit.

(2) Carry out a careful examination of the injured eye as detailed below.

(3) Attend carefully to the immediate cleansing treatment of the eye.

(4) In every case of prolapse of the uvea (iris, ciliary body, or choroid) the ophthalmic surgeon should be sent for.

The arrangements of the medical service are now such that an eye specialist is readily accessible at every Casualty Clearing Station, and his services ought to be obtained whenever the slightest difficulty or doubt arises. Whenever possible, eye cases should be evacuated to the Base Ophthalmic Hospital at the earliest opportunity.

Early Treatment.—The lids and parts around the eyes should be thoroughly cleaned and the conjunctival sac washed out with sterilised boric acid or saline solution. Some 1 per cent sterilised atropin ointment is inserted between the lids. If no ointment is available, the ophthalmic atropin tabloids may be used, but they have the disadvantages that they may not be sterile, that they cause some irritation, and that their manipulation is difficult.

The injured eye is covered with a pad and bandaged.

If no immediate operative treatment is required, the washing of the eye is repeated every six or eight hours until evacuation.

The Examination of the Injured Eye.—(1) *General Inspection.*—A search is made for wounds in the soft parts around the eye, and the presence or absence of proptosis is noted.

(2) *Local Inspection.*—The cornea and sclera are examined for wounds or foreign bodies, and prolapse of iris, choroid, or ciliary body is noted. The anterior chamber is inspected for hyphaema, hypopyon, or foreign body. The iris is examined for the discoloration or muddiness which indicates iritis or panophthalmitis. It is noted whether the pupil is circular or irregular, whether there is a rupture of the sphincter, a perforation or a tearing away of the iris at its periphery (iridodialysis). The reaction of the iris to light is tested.

An attempt should be made to test the vision of the affected eye and the tension of the eyeball is noted. If an ophthalmoscope is at hand and suitable illumination can be arranged, the following points should be observed:

(*a*) The red reflex and whether it can be obtained in all or only in certain directions.

(*b*) The lens for dislocation or perforation by a foreign body.

(*c*) The vitreous for haemorrhage or foreign body.

(*d*) The fundus for haemorrhage, detachment, rupture of choroid, or foreign body.

Finally an X-ray photograph may be of great value.

Having completed the examination, the medical officer decides whether the case demands immediate operative interference or not. It is most important to decide at once whether or no there is any possibility of a foreign body having lodged in the eye. If this is suspected, the case should be sent forthwith by special ambulance car to a Base Hospital where there is a Giant magnet. If the patient is too ill to be moved, the ophthalmic specialist should be sent for; he will bring with him one of the new large hand magnets, and if such a magnet is not available the mobile magnet car should be requisitioned. These cases should have the benefit of the magnet treatment at the earliest possible date.

Apart from drainage and clearing up of the orbital wounds, the only operative interference demanded will be excision of the eyeball. If the iris is prolapsed and infected, and some considerable time must elapse before the patient can be evacuated to an ophthalmic centre, it may be justifiable to perform an iridectomy, but this should only be done under exceptional conditions and the services of the ophthalmic specialist should be obtained.

Practically speaking, the only indication for excision of the eyeball at this stage is rupture of the globe with complete disorganisation. Sympathetic ophthalmia does not occur earlier than ten days after injury, and rarely before three weeks. Panophthalmitis is also a comparatively late complication, and therefore these possibilities have very rarely to be considered at this stage.

When both eyes are ruptured and blind, no operation should be undertaken immediately unless there is great pain or for some reason life is endangered by keeping the remains.

The knowledge that both eyes have been removed often produces extreme depression at a time when every effort should be made to improve the patient's vitality.

An exception should be made in those cases in which one eye is ruptured and the optic nerve of the other divided by a transverse wound. In those cases the ruptured eye should be removed to prevent the possibility of sympathetic ophthalmia in its fellow.

Method of Excision of the Eye.—In view of the widespread infection of war wounds, it is unwise to excise the eye in the ordinary way with division of the optic nerve. If this is done there is a risk of septic meningitis developing. The following technique is therefore to be recommended :—

The contents of the globe are completely eviscerated. The retina and choroid are thoroughly scraped away to avoid any possibility of sympathetic ophthalmia. The muscles are divided. The sclerotic is pulled forwards and divided far back so that only a frill is left around the intact optic nerve.

When the opening in the globe is small the conjunctiva and muscles are divided first. The cornea is then cut away and evisceration proceeded with. If there is panophthalmitis, the eyeball is eviscerated before incising the conjunctiva and dividing the muscles. In this way infection of the orbit is prevented.

After excision of the eye, packing of the orbit with gauze is both unnecessary and harmful. If there is any haemorrhage, all that is required is to bandage a pad firmly over the closed lids.

CHAPTER XVIII

TETANUS

In the early months of the war it was found that the incidence of tetanus among the wounded was higher than had been anticipated from the experience of recent campaigns.

This apparently depended upon two causes—the greater severity of the wounds and the heavy contamination of the soil over which the fighting occurred. Owing to the highly manured character of the soil, tetanus spores abound, and should the bacilli which develop from these spores succeed in establishing themselves in the wound they give rise to a toxin which from its affinity for nervous tissue produces the well-known symptoms of the disease.

Symptomatology.—The toxin acts principally on the nerve centres in the spinal medulla, to which it travels from the focus of infection by way of the motor nerve fibres. Its first effect on the motor ganglia of the cord is to render them hypersensitive, so that they are excited by stimuli which under ordinary conditions would produce no reaction. As the toxin accumulates, the reflex arc is affected, with the result that when a stimulus reaches the ganglia a motor discharge takes place which spreads by ascending and descending collaterals to the reflex apparatus of the whole cord. As the toxin spreads, it causes both motor hypertonus and higher excitability, which accounts for the tonic contraction and the clonic spasms characteristic of tetanus.

Early Features of the Disease.—From the point of view of success in treatment the prompt recognition of the early symptoms of the disease is important, though often such a recognition is by no means easy.

The early indications may be of a general nature, such as irritability, insomnia, increased reflex irritability, or muscular tremors. Sometimes the manifestations are local in the shape of pain in or near the wound, increased hardness or rigidity of the muscles around the wound, with twitching of various muscles excited by slight stimuli. Other early symptoms are pain and stiffness in the neck, sore throat, difficulty in swallowing, difficulty in micturition, and evidences of reflex spasm or paralysis, headache, diffuse backache, and excessive yawning.

In a large number of cases the toxin appears to reach the spinal cord primarily by the nerves which are in connection with the seat of the injury, and hence the motor nerve cells governing the muscles round about the wound will be the earliest affected, such affection showing itself in the form of spasticity and increased reflex excitability of the muscles near the wound. In some cases these symptoms may precede other general symptoms of tetanus by many hours. It is important, therefore, that the muscles in the vicinity of the wound should be examined whenever dressings are removed, and the occurrence of rigidity or local increased reflex response to gentle tapping or pressure be immediately noted.

Clinical Features of the Established Disease.—These are too well known to require a detailed description. They include the stiffness of the jaw muscles, the risus sardonicus, the spreading tonic contraction of the neck muscles, of the diaphragm, and anterior abdominal wall, later of the muscles of the back, thorax, and limb. To the tonic contractions there become added clonic contractions, at first slight and transient, but afterwards becoming more frequent and severe. The temperature is generally raised, and the pulse is quickened.

Treatment. — Preventive. — (*a*) *General Measures.* — The thorough surgical toilet of the wound is an important measure in the prevention of tetanus. The details of such wound toilet have been already described.

(*b*) *Special Measures.* — By these one means the prophylactic use of the tetanus antitoxin. Here it must be mentioned that the possible victims of tetanus are not limited to wounds classed as battle casualties, but include accidentally injured, burns, and trench feet.

In all of these the prophylactic dose of tetanus antitoxin should be inoculated subcutaneously at the earliest possible moment, no matter how trivial the injury may appear to be.

The customary prophylactic dose is 500 units, one-third of the contents of a 10-c.c. phial containing 1500 units. In severe contaminated wounds a larger initial dose is indicated: 1000 or 1500 units should be given. In the case of wounded men who have "lain out" for several days, and in whom the danger of infection is much enhanced, the primary injection should never be less than 1500 units. As the passive immunity conferred by the initial dose of the antitoxin quickly diminishes, and as it is well known that tetanus spores may retain their vitality for a prolonged period, a repetition of the initial dose at regular intervals is advocated, and second, third, and fourth doses of 500 units at intervals of seven to nine days should be given. An exception to this rule is made in the case of men so slightly wounded that they are to be returned to duty; in such the second prophylactic dose is sufficient.

The system of small repeated doses has been objected to on the grounds that with each successive injection the antibodies are more quickly excreted by the body.

The possibility of a secondary operation exposing the patient to the dangers of an attack of tetanus by disturbing a focus in which spores may have been lying dormant should not be forgotten. It is well, therefore, when such an operation is

contemplated, to give a preliminary injection of 500 units subcutaneously two days beforehand. If a more rapid effect is required, the injection is given intramuscularly the day before operation.

The Treatment of the Established Disease.—In order to obtain the best results, whatever system of treatment may be adopted, it is essential that such treatment should be begun at the earliest possible opportunity.

The various lines of treatment may be dealt with under the following headings.

(*a*) *Local and Surgical Measures.*—Any attempt to excise or otherwise interfere with the wound is contra-indicated. The mere opening up of the wound may provide additional paths for the absorption of toxin, but against this one must put the fact that the retention of discharge or of infected foreign bodies in the wound will probably favour the continuance of the infection.

The application of strong antiseptics such as pure carbolic is of very doubtful value.

The irrigation of the wound with oxidising agents, *e.g.* H_2O_2, when this can be done without undue disturbance, will tend to neutralise locally formed toxin.

(*b*) *General Measures.*—The patient should be kept in a quiet darkened room in which an equable temperature is maintained. All causes of external stimuli are avoided, and with this in view it has been suggested that the eyes should be bandaged, the ears plugged with wool, and the feet of the bed placed upon rubber discs. He should be kept under the influence of $\frac{1}{4}$ gram of morphia administered every four hours.

The patient's strength is maintained by adequate fluid nourishment given in small quantities at frequent intervals, milk, eggs, soup, beef-tea, brandy, etc., being given if necessary in teaspoonful doses between the spasms. Nasal feeding

should be avoided owing to the disturbance of the patient, and nutrient enemata, besides the difficulty in getting them retained owing to the spasms, are a very poor substitute for feeding by the mouth. The patient's chance of life depends upon his strength and nutrition being kept up, and these rapidly fail on so-called nutrient enemata.

(*c*) *Anaesthetics and Sedatives.* — The value of chloroform is well recognised as a means of relieving the spasms.

Chloral hydrate, potassium bromide, and morphia are useful in controlling the contractions. Chloral is perhaps the best, and the patient should rarely have less than 150 grains in twenty-four hours. When he is unable to swallow, it should be given by the rectum.

When rest and sleep have been procured by the help of drugs, and the recurrent spasms cease, it is necessary to keep a watch upon the pulse, the respiration, and the colour of the lips, face, and hands. If the breathing should become stertorous or irregular, or the pulse evidently fails in strength or becomes irregular, or if cyanosis appears, it is possible that too much hypnotic has been used and stimulant treatment may be required.

(*d*) *Carbolic Acid and Magnesium Sulphate.*—Bocelli recommends the injection of 20 c.c. of 1 in 100 solution of carbolic acid into the subcutaneous tissue every four hours during the period that the contractions persist.

The method has been found quite unreliable, and no case in France has lately been treated by it.

The intrathecal injection of 10 c.c. of a 15 per cent solution of magnesium sulphate has proved beneficial in alleviating the severity of the spasms, but does not appear to have a curative effect. The general feeling is now against this method of treatment.

Tetanus Antitoxin.—The value of the anti-tetanic serum as a means of counteracting the toxins already in circulation

is still in doubt, but it may be said that this is meanwhile the only rational treatment offering any hope of cure.

In carrying out the procedure, certain cardinal principles should be kept in view: the antitoxin treatment must be started immediately after the appearance of the first suspicious signs of tetanus; the dosage of the antitoxin must be high, and its use must be maintained well into convalescence.

Channels of Administration.—Those most commonly employed are the intrathecal, intravenous, subcutaneous, and intramuscular.

1. *Intrathecal Method.*—The memorandum issued by the War Office Tetanus Committee makes the following statement:

"In acute general tetanus the best method of treatment lies in the earliest possible administration of large doses of antitoxin serum by the intrathecal route repeated on two, three, or four days in succession and combined if thought advisable with intramuscular injections."

Theoretically this method is sound, but experience has shown that to afford the best results the condition must be diagnosed sufficiently early to allow of its prompt application. As large a primary dose as possible must be given in order to neutralise the "floating" toxin. It may be said that in man the efficacy of this method is as yet unproved.

2. *Intravenous Method.*—Direct intravenous injection of the antitoxin is obviously the most rapid means of attempting to neutralise the circulating toxins, but it has the disadvantage that if previous serum inoculations have been given, there is a very real risk of anaphylaxis occurring. The results of this method when used in France have been disappointing, and the procedure is not recommended.

3. *Subcutaneous Method.*—This route is very frequently employed. By it large amounts can be given at frequent intervals, and by it the degree of circulation of the antitoxin

in the blood stream can be maintained at a high level. It has the disadvantage that absorption is slow.

4. *Intramuscular Method.*—Absorption by this channel is more rapid than by the subcutaneous route; by it also the serum can be introduced at various points around the wound in which the toxin is being formed—a very real advantage.

Dosage employed.—Whatever route is chosen, the dosage must be large and constantly renewed. The ideal aimed at is as early saturation of the tissues as possible and a maintenance of this saturation until all danger is passed.

In the first forty-eight hours 50,000 units or more may be given intramuscularly, and the daily dosage, which naturally depends on the progress of the case, may decline until towards the seventh or eighth day; doses of from 1000 to 2000 units may be given on alternate days until all symptoms disappear. In view of possible relapse, the treatment must not be stopped too soon.

If the intrathecal route is chosen, the concentrated serum should be employed; this contains 8000 units in a 10-c.c. ampoule, and 16,000 units is given as a primary injection. At the same time it is well to combine the intrathecal injections with large intramuscular or subcutaneous injections. For this purpose the ordinary strength serum is employed: 1500 units per 10-c.c. ampoule.

For the treatment of local tetanus daily subcutaneous injections of 5000 units may suffice, but if symptoms are becoming generalised an intrathecal injection should be given.

Anaphylaxis. — When the intrathecal and intravenous routes are employed there is a danger of anaphylaxis occurring if an interval of more than ten days has elapsed since the last dose of antitoxin. With the subcutaneous and intramuscular methods the danger appears to be almost negligible.

In cases in which anaphylaxis is feared, the serum is given

by the so-called "fractional" method. A preliminary inoculation of two or three drops is given in dilution; this is followed in five minutes by 0·5 c.c. If no untoward symptoms result, it is said that the full dose may safely be inoculated ten minutes later.

Administration of the antitoxin under chloroform anaesthesia is said to be a safeguard against anaphylaxis, but this has been questioned.

If symptoms of anaphylactic shock occur, such as collapse, pallor, sweating, air hunger, rapid pulse, cyanosis, and respiratory failure, adrenalin is said to be useful. If the symptoms are urgent, the drug is given intravenously in high dilution. In less severe cases it is given subcutaneously in a dose of five minims of a 1-1000 solution.

Pituitrin in a dose of 1 c.c. is said to relieve the collapse and to relax the bronchial spasm if given immediately on the appearance of the symptoms.

INDEX

Abdomen, wounds of, 144
examination in, 153
Abdominal wounds, complications of, 163
diagnosis of, 152
etiology of, 146
frequency of, 145
mortality of, 155
operation for, 161
pathology of, 147
prognosis of, 154
treatment, early, 145
post-operative, 163
Abdomino-thoracic wounds, 207
treatment of, 208
Abel, plasma, importance of, 270
Acapnia, 7
Acidosis in shock, 13, 14, 15
Acriflavine paste, 72
Advanced Dressing Station, 11
Agglutination, blood transfusion in, 276
Aid Post, Regimental, 10
Alkali of blood in shock, 13
Alkaline solutions in shock, 19, 22
Amputations, 262
gas gangrene in, 260
lower extremity, 267
methods of, 264
sites of, 266
upper extremity, 266
wounds of knee-joint in, 137
Anaerobes in wounds, 28
Anaesthesia, head injuries in, 220
local, Gray's syringe for, 199
nitrous oxide and oxygen, 21, 22
shock in, 21
tetanus in, 308
wounds of chest, 199
Anaphylaxis, 15, 310
Aneurysms, false, 246, 251
Angled splint, fractures of femur for, 110
Ankle, gunshot wounds of, 143
splint for, 118
Anti-coagulant, blood transfusion in, 287
Antiseptics, 62
brain operations in, 224
older, 63
paste, 72
powders, 72
synthetic dyes, 70
Anti-tetanic serum, 3, 308
Area, operation, 5
Arm, amputation of, 266
Arrangement of C.C.S., 1
Arteriorrhaphy, 248

B.I.P.P., 72
Bacillus aerofetidus, 28
aerogenes capsulatus, 27
fallax, 28
histolyticus, 28, 253, 254
oedematicus, 28, 253, 254
putreficus coli, 29
pyocyaneus, 29
sporogenes, 28, 253, 254
tertius, 28
tetanus, 28
Welchii, 28, 253, 254
Balkan frame splint, fractures of femur, for, 110
Bashford, pathology of gunshot wounds, 34
Bayliss, acidosis in shock, 13
gum acacia solution, 273, 274
shock, 15

Bazett, blood transfusion, 282
Bell, perforation of hollow viscera, 148
Bile ducts, wounds of, 180
Bladder, wounds of, 178
Blake, compound fractures of femur, 108
Blankets, arrangement of, 5
Blood pressure, in head injuries, 218
in shock, 10, 18
Blood substitutes, 271
Blood transfusion, 275
paraffin-coated receiver, 285
reaction after, 279
syringe canula method, 283
two-way tap syringe, 284
Blood-vessels, ligature of, 250
wounds of, 241
treatment, 247
Boise, theory of shock, 8
Bombs and grenades, 25
wounds by, 32
Bond's paste, 72
Bones, etiological considerations, 75
gunshot injuries of, 74
physiological considerations, 74
sepsis in repair of, 80
Bonnette Eclipse X-ray table, 197
Borchgrevink, splint for fractured femur, 128
Bowlby, mortality in compound fracture of femur, 97
Brain, injuries to, 213
Brilliant green, 71
Brown, blood transfusion, 285
Browning, brilliant green, 71
Bullets, British, French, and German, 23
Buttock wounds, complications of, 4

Cabot, reaction after blood transfusion, 280
Campbell, knee-joint, infections of, 139
Cannon, shock, 20
Capillary count in shock, 12
Carbolic, 63
in tetanus, 308
Carrel-Dakin method, 49, 50
after-care of wound, 54
bacteriologic examination in, 55
closure of wound, 58
Carrel-Dakin method (*contd.*)—
disadvantages of, 59
materials for, 53
Carrel-Gentile syringe, 223
instillation tubes, 51
technique, 40
Cases, distribution of, 4
examination of, 4
lying, 3, 4
sitting, 3
Casualty Clearing Station, 11
accommodation in, 2
arrangement of, 1
definition of, 1
organisation of, 1
staff of, 2
treatment of wounds at, 38
Channels of distribution of cases, 4
Character of general wounds, 29
Cheatle, synthetic dyes, 70
Chest, wounds of, 190
Chloramin method of treatment, 60
Chloramines, 70
Chlorcosane, 61
Chopart's amputation, 267
Clarke's splint, fracture of humerus, for, 126
Classification, general wounds, 26
wounds of chest, 190
Clavicle, fracture of, 129
Clearing Hospital, 1
Cobbett, theory of shock, 8
Codavilla's extension pins, 91
Colon septicaemia, 175
wounds of, 162
Comminuted fractures, 77
Compound fracture of femur, 97
Contact fracture, 76
Contused wounds, 26
Cowell, thoracotomy, 201
Creuze, transfusion, 275
Crile, shock, theory of, 7
Croft's splint, 87
Cushing, head injuries, 211
trepanation, 222

Dakin's solution, 64, 67
Dale, shock, 15
Daufresne, technique, 67
Daufresne-Dakin, solution, 49
Delorme, comminuted fractures, 77

Depôt antiseptic, 39
Dessane, X-ray table, 197
Dextrin solution, 272
Diagnosis, abdominal wounds, 152
fracture, 81
shock, 15
spinal injuries, 231
Di-chloramin T., 60, 70
Disinfection, primary, of wounds, 37
Distribution of cases, 4
Donor, blood transfusion in, 276
Dorrance, arteriorrhaphy, 249
Double transfixion apparatus for extension, 93
Dreyer, blood transfusion, 282
Drummond, wounds of bladder, 180
Dunn, wounds of liver, 181
Duval, organisms in chest wounds, 194
wounds of chest, 190

Edinburgh preparations, 64
Elbow-joint, amputation through, 266
sepsis in, 142
wounds of, 141
Elliot, haemorrhage in chest wounds, 193
perforation of hollow viscera, 148
Emphysema, subcutaneous, 205
Eupad, 64, 66
Eusol, 64
composition of, 65
preparation of, 65
Evacuation, chest injuries, of, 205
head injuries, of, 228
spinal injuries, 237
Examination of cases, 4
of head injuries, 217
Expectorant, sedative, 203
stimulant, 203
Extension, fracture of both bones in, 121
methods of, in fractures, 90
Eye, examination of, 301
excision of, 303
injuries to, 300

Femur, compound fracture of, 97
double, 116
first-aid splint in, 100
mortality in, 97
prognosis in, 97
Femur, compound fracture of (*cont.*)—
splint for, 98
treatment in, 98
Fibula, fracture of, 117
Field Hospital, 1
Fildes-Raychman, synthetic dyes, 70
Fingers, amputation of, 266
Finochietto, apparatus in fractures of femur, 107
extension in fractures of both bones, 121
stirrup extension, 94
Fissured fracture, 76
operation in, 226
Flavine, 71
Fleming, micro-organisms, 27, 28
Foot, amputation of, 267
fractures of, 123
Footpiece, fractures of leg, in, 122
Forearm, amputation through, 266
Fractures, classification of, 76
clavicle, of, 129
comminuted, 77
contact, 76
diagnosis of, 81
displacement in, 80
extension in, 88
femur, of, 97
femur, double, 116
fissured, 76
foot, of, 121
gutter or groove, 77
humerus, of, 124
lower end, 128
immobilisation of, 87
indirect violence, by, 78
jaw, of, 130
metacarpals, of, 129
operative treatment in, 96
patella, of, 130
phalanges, of, 129
physical signs in, 81
prognosis in, 83
repair of, 78
scapula, of, 130
skull, of, 215
symptoms of, 81
treatment of, 84
later treatment of, 96
upper limb, of, 124
X-ray examination in, 82

Fragments, shell, 23
Frequency, abdominal wounds, 145
Fullerton, blood transfusion, 282
wounds of bladder, 180

Gall bladder, wounds of, 180
Gangrene, gas, 15, 253
Gas gangrene, 15, 253
clinical features of, 257
prevention of, 259
treatment of, 259
varieties, 257
Gask, wounds of chest, 190
Gelatine, blood substitute, as, 272
Gilmour, brilliant green, 71
Glucose solution, 272
Gray, salt pack method, 48
syringe for local anaesthesia, 199
Green-Armytage, perforation of hollow viscera, 148
Grenades, 25
Grimberg, transfusion, 275
Groove fracture, 77
Groups, blood in transfusion, 277
Guillotine amputation, 264
Gum acacia solution, 18, 22, 273
Gunshot wounds, abdomen, of, 144
ankle, of, 143
bones, 74
clinical features of, 35
elbow, of, 141
hip, of, 142
microscopic pathology, 34
morbid anatomy, 33
operative interference in, 39
pathology of, 32
shoulder, of, 142
treatment of, 37
Gutter fracture, 77
wounds, 26

Haematoma, perivascular, 245
Haemolysis, blood transfusion, in, 276
Haemorrhage, 15, 241
chest wounds, in, 193
gunshot wounds, in, 36
primary, 245
recurrent, 242
secondary, 242
Haemothorax, 193
treatment of infected, 204
Haemothorax, treatment of (*contd.*)—
non-infected, 203
Hand, amputation of, 266
Haycraft, primary suture, 41, 42
Head injuries, 211
evacuation of, 228
examination of, 217
operation in, 219
prognosis in, 218
retention of urine in, 237
treatment of, 219
Hedon, preserved red blood corpuscles, 295
Henry, anaerobes in wounds, 28
haemorrhage in chest wounds, 193
infection in chest wounds, 194
perforation of hollow viscera, 148
Hernia, diaphragmatic, 209
Heusner's glue, 89
Hey-Groves, extension in fracture of both bones, 121
femur, double fracture of, 117
metacarpals, fracture of, 129
modification of Hodgen's splint, 112
treatment of fractures, 85
High explosive shells, 24
Hip-joint, amputation through, 268
gunshot wounds of, 142
Hodgen's splint, 112
Hodge's cradle for fractures of femur, 115
Hogan, gelatine-containing fluids, 272
Holmes, wounds of sinus, 227
Hooker, blood transfusion, 285, 287
Horse serum, blood substitute, as, 272
Hospital, Clearing, 1
Field, 1
Hull, salt pack method, 49
Humerus, fracture of, 124
lower end, 128
Hypertonic salt solution, 19, 64
Hypochlorites, 64

Ice tongs, method of extension, 94
Ileus duplex, 164
Infection, chest wounds, in, 194
head injuries, in, 214
wounds, of, 26
Infusion, 269

Injuries, spine, 229
Instillation tubes of Carrel, 51
Intestine, wounds of large, 174
small, 167
Iridodialysis, 301
Iritis, 301
" Isle of Man " incision, 221

Jaw, fracture of, 130
Joint, elbow-, 141
knee-, 131
wounds of, 130
Jones, abduction frame, 115
crab splint, 123 ;
splint for fracture of humerus, 126
Jurevitch, preserved red blood corpuscles, 295

Keith, shock, 15
Kempton, blood transfusion, 285
Kidney, wounds of, 186
Knee-joint, amputation in wounds of, 137
through, 268
classification of wounds of, 133
operative measures on, 133
treatment of wounds of, 131
infection in, 138
wounds of, 131
Kocher, mobilisation of intestine, 189

Lacerated wounds, 26
Landois, donors in blood tranfusion, 276
Landsteiner, donors in blood transfusion, 276
Lee, donors in blood transfusion, 276
Leg, amputation of, 267
Lisfranc's amputation, 267
Liver, wounds of, 180
Locke's solution, 47
Lorraine Smith, eusol, 64
Lumbar puncture, 228
Lyle, Carrel-Dakin technique, 53
Lying cases, 3, 4

M'Clure, donors in blood transfusion, 276
M'Ewan, bone-forming power of periosteum, 75
M'Nee, pathology of gunshot wounds, 34
Magnesium sulphate, tetanus, treatment of, 308
Makins, blood-vessels, wounds of, 245
haemorrhage, secondary, 243
viscera, perforation of hollow, 148
Malachite green, 71
Meltzer, theory of shock, 8
Mercurophen, 63
Mercury, 63
Metacarpals, fractures of, 129
Meyer, magnesium hypochlorite solution, 70
Micro-organisms, prevalence of various, 27
Middeldorpf's splint, 125
Morphia, shock, in, 17
Mortality, compound fractures of femur, 97
wounds of abdomen, 144, 155
of bladder, 180
chest, 206
intestine, large, 177
small, 174
liver, 182
pancreas, 184
spleen, 186
stomach, 167
Mortars, trench, 25
Moss, donors in blood transfusion, 276
Mouvement de bascule, 29
Mummery, theory of shock, 7

Nephrectomy, 187
Nerves, lesions of peripheral, 239
Nitrous oxide anaesthesia, 21, 22

Oesophagus, wounds of, 164
Oligaemia, 8
Operation, abdominal wounds, 161
area, 5
chest wounds, 199
fissured fracture, 226
gunshot wounds, 39
head injuries, 219
knee-joint wounds, 134
shock in, 19
spinal injuries, 233
Operative shock, 21

Page, splint for fracture of femur, 108
Pancreas, wounds of, 183
Panophthalmitis, 301
Pastes, antiseptic, 72
Patella, fracture of, 130
Pathology, gas gangrene, 252, 255
gunshot wounds, 32
of abdomen, 147
bladder, 178
blood-vessels, 244
chest, 191
intestine, large, 174
small, 168
liver, 180
rectum, 177
spleen, 184
shock, 12
Penetrating wounds, 26
Perforating wounds, 26
Perforation, hollow viscera, of, 148
Peyton, preserved red blood corpuscles, 295
Phalanges, fractures of, 129
Pirogoff, amputation, 267
Pneumothorax, 197
treatment of, 203
Powders, antiseptic, 72
Pre-operation ward, 4, 5
Preventive treatment, shock of, 16
tetanus, 306
Primary shock, 9, 10
Primary suture of wounds, 38, 40
technique, 41
tissue staining in, 43
wound disinfection, 37
Prognosis, compound fracture of femur, 97
fracture, 83
shock, 16
wounds of abdomen, 154, 157
of bladder, 180
chest, 206
head, 218
intestine, large, 177
small, 174
knee-joint, 133
liver, 182
pancreas, 184
spine, 231
spleen, 186
stomach, 167
Projectiles, types of, 23
Proteolytic group, 28
Pulse rate, abdominal wounds, in, 159

Raiziss, mercurophen, 63
Reception area, 3
rooms, 3
Rectum, wounds of, 177
Red blood corpuscles, injection of preserved, 295
Regimental Aid Post, 10
Resection, intestine of, 172
Resuscitation wards, 4, 6
Richardson, shock, 15
Rifle bullet wounds, 29
Ringer's solution, 47, 271
Robertson, blood groups, 277
citrated blood transfusion, 289
preserved red blood corpuscles, 295
Rosenberg, preserved red blood corpuscles, 295
Rosengarten, method of, 69
Rous, red cells, importance of, 270
preserved, 295
Roux, amputation of, 267
Rowntree, plasma, importance of, 270
Rupture, viscera, of, 149
Rutherford-Morrison, B.I.P.P., 72

Saccharolytic group, 28
Saline, hypertonic, 19, 271
Salt pack, 48, 49, 64
Sampson-Handley, post-operative peritonitis, 164
Sargent, wounds of sinus, 227
Satterlee, blood transfusion, 285, 287
Saxton-Pope, blood transfusion, 282
Scalp, wounds of, 215
Scapula, fracture of, 130
Schomberg-Kohner, mercurophen, 63
Secondary wound shock, 11
Sepsis, bone repair, in, 80
elbow-joint of, 142
Serum, anti-tetanic, 3, 306, 308
Shell fragments, 23
high explosive, 24
wounds, 31
Shock, acidosis in, 13
amputations in, 262
anaesthetic in, 21
blood pressure in, 10, 11

Shock (*contd.*)—
capillary count in, 12
clinical history of, 9
concentration of blood in, 13
diagnosis of, 15
H. Ion in, increase of, 13, 14
operation in, 19
operative, 21
pathological findings in, 12
predisposing factors to, 8
primary wound, 9, 10
prognosis in, 16
secondary wound, 11
stasis of blood in, 13
surgical, 7
theories of origin of, 7
transfusion of blood in, 18, 22
treatment of, 16, 17
operative, 21
Shoulder, gunshot wounds of, 142
Shrapnel, 24
bullet wounds, 31
Sinclair, ankle splint, 118
extension in fracture of both bones, 121
fractures of lower limb, 123
glue, 89
prop, 107
skate, 107
suspension of fractures of femur, 108
Thomas knee splint, adjustment for, 106
Sinus, wounds of, 227
Sitting cases, 3
Skull, fracture of, 215
injuries to, 212
Sodium chloride, hypertonic, 19, 271
physiological, 271
South African Campaign, 1
Spinal injuries, 228
clinical examination of, 231
treatment of, 232
by operation, 233
Spleen, wounds of, 184
Splint, abduction frame, 115
crab, 123
cradle, fixed wire, 112
fractures of femur, 99
angled, 110
Balkan frame, 110
Hodgen's cradle, 112
Splint, fractures of femur (*contd.*)—
Page's, 108
special, 114
Wallace-Maybury, 109
of foot, 123
of humerus, 125, 126
Borchgrevink, 127
Middeldorpf's, 125
wound of knee-joint, 132, 139, 140
Staphylococcus, 27
Steinmann's pins, 91
fractures of femur, in, 107
Stokes, pathology of gunshot wounds, 34
Stokes-Gritti, amputation of, 268
Stomach, wounds of, 165
Streptococcus, 27
faecalis, 29
Stump, qualities of a good, 264
Substitutes, blood, for, 271
Suture, intestine, of, 170
primary, 38, 40
Syme, amputation of, 264, 267
Syndrome of spasticity, 216
Synthetic dyes as antiseptics, 70
Syringe, Carrel-Gentile, 223

Technique, chest operations, 200
head operations, 220
primary suture, 41
transfusion, 275
Temperament, nervous, 9
Tetanus, 304
anaphylaxis in, 15, 310
antitoxin, 306, 308
bacilli in wounds, 28
clinical features, 305
symptoms of, 304
treatment of, 306
Thigh, amputation through, 268
Thomas outfit for compound fracture of femur, 102
splint, drill for applying, 102
fracture of humerus, 127
knee splint, after operation, 105
compound fracture of femur, 100
Thumb, amputation of, 266
Tibia, extension in fractures of, 121
fractures of, 117
Tissue staining in primary suture, 43

Toes, amputation of, 267
Tourniquet, 5, 241
Transfusion, 269
  direct, 282
  methods of, 281
  of blood, 275
    citrated, 289
    methods, choice of, 299
    shock, in, 18
Treatment, chloramin method, 60
  compound fracture of femur, 98
  fractures, general principles, 84
  gas gangrene, 259
  head injuries, 219
  hernia, diaphragmatic, 210
  shock, 16, 17
    operative, 21
  spinal injuries, 232
  tetanus, 306
  wounds, 23, 37
    at C.C.S., 38
    of abdomen, 145, 160
    abdomino-thoracic, 208
    bladder, 179
    blood-vessels, 247
    chest, 198
      post-operative, 202
    duodenum, 188
    intestine, 169
    kidney, 187
    knee-joint, 131
    liver, 182
    rectum, 177
    spleen, 185
    stomach, 166
Trench mortars, 25
Trepanation, 221
Trypaflavine, 71
Tuffier's tubes, 250
Turner, plasma, importance of, 270
  preserved red blood corpuscles, 295
Types of projectiles, 23

Ureter, wounds of, 186
Urotropin, 227

Vale, theory of shock, 8
Van Slykes' apparatus, 20
Veratrum viride, 8
Vibrion septique, 253
Viscera, frequency of wounds of, 151

Wallace, abdominal wounds, frequency of, 146
  wounds of intestine, small, 150
    of pancreas, 183
      scalp, closure of, 225
      viscera, frequency of, 151
Wallace-Maybury splint, 109
Ward, pre-operation, 4, 5
  resuscitation, 4, 6
Weil, citrated blood, 288, 289
Wilson, red cells, importance of, 270
Wilson-Hey, brilliant green, 73
  tissue staining, 43
Wounds, 26
  character of, 29
  classification of, 26
  infection of, 26
  of abdominal organs, 208
    abdomino-thoracic region, 207
    bladder, 178
    blood-vessels, 241
    brain, closure of, 224
    chest, 190
    colon, 162
    duodenum, 188
    head, 211
    intestines, large, 174
      small, 167
    joints, 131
    kidney, 186
    liver, 180
    oesophagus, 164
    pancreas, 183
    rectum, 177
    sinuses, 227
    spleen, 184
    stomach, 165
    ureters, 186
  treatment of, 23
Wright, technique of, 40, 45, 48

X-rays, chest wounds, in, 197
  fracture, in, 82
  table, Bonnette Eclipse, 197
  wounds of abdomen, 154

Yandell Henderson, theory of shock, 7

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